Colliders and Cosmology

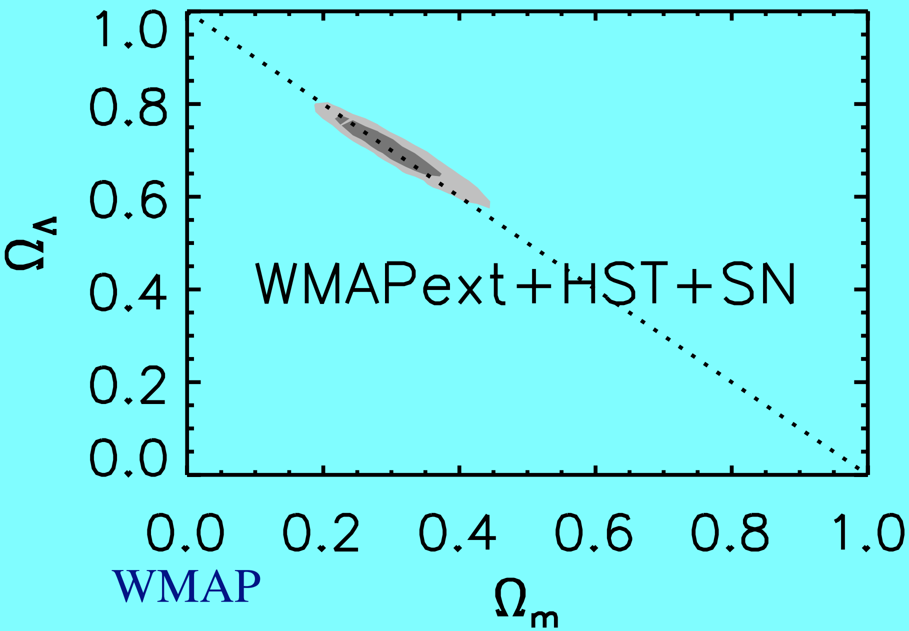
Dark Matter in variations of constrained MSSM models:
A comparison between accelerator and direct detection constraints

- CMSSM
- mSUGRA
- Sub-GUT
- NUHM

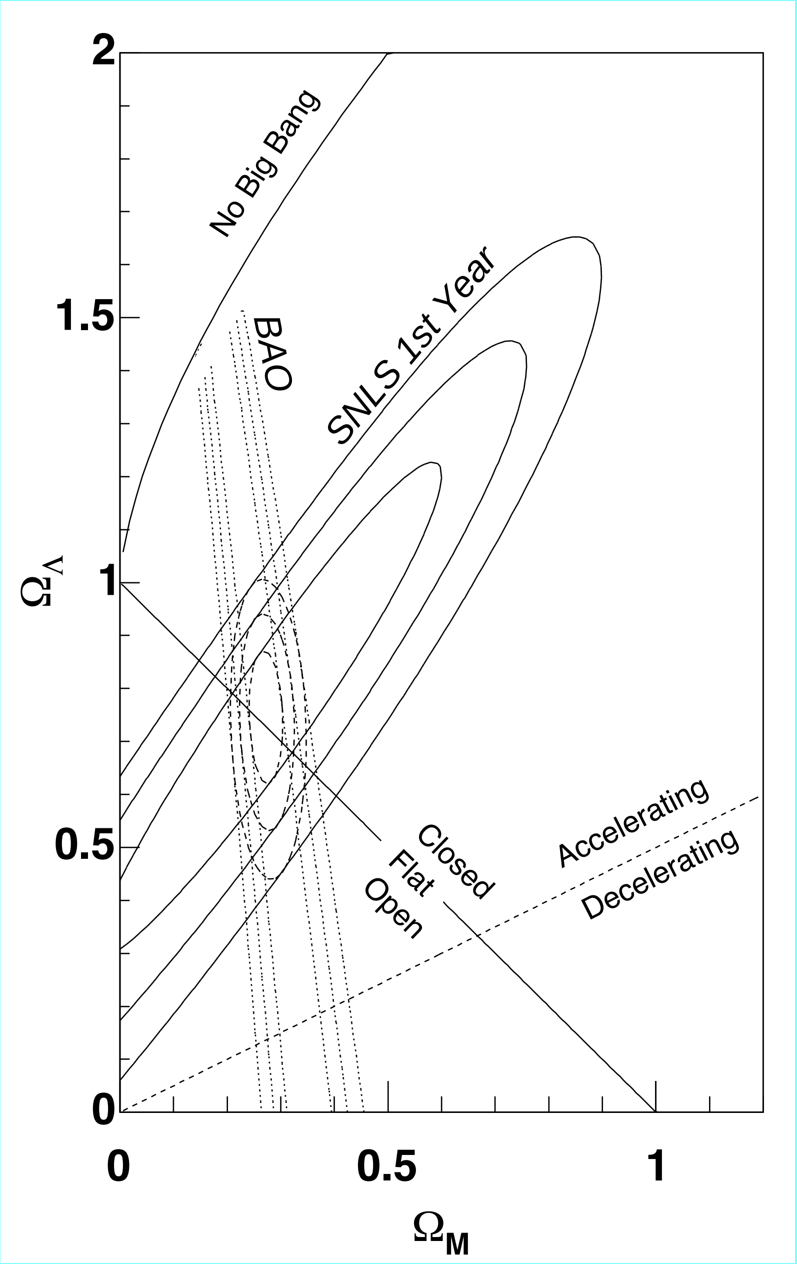
with: Ellis, Hahn, Heinemeyer, Sandick, Santoso, Spanos, Weber, Weiglein

Evidence for Dark Matter

Clowe et al.



WMAP



SNLS

How Much Dark Matter

WMAP 3 Spergel etal

Precise bounds on matter content

How Much Dark Matter

WMAP 3

Spergel etal

Precise bounds on matter content

$$\Omega_m h^2 = 0.1265^{+0.0081}_{-0.0080} \qquad \Omega_b h^2 = 0.0223 \pm 0.0007$$

$$\Omega_{cdm} h^2 = 0.1042^{+0.0081}_{-0.0080}$$

or

$$\Omega_{cdm}\, h^2 = 0.0882 - 0.1204 \quad (2\,\sigma)$$

Unification Conditions

- Gaugino masses: $M_i = m_{1/2}$
- Scalar masses: $m_i = m_0$
- Trilinear terms: $A_i = A_0$

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predict μ, B

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mSugra Conditions

- Gaugino masses: $m_{3/2} = m_0$
- Bilinear term: $B_0 = A_0 - m_0$

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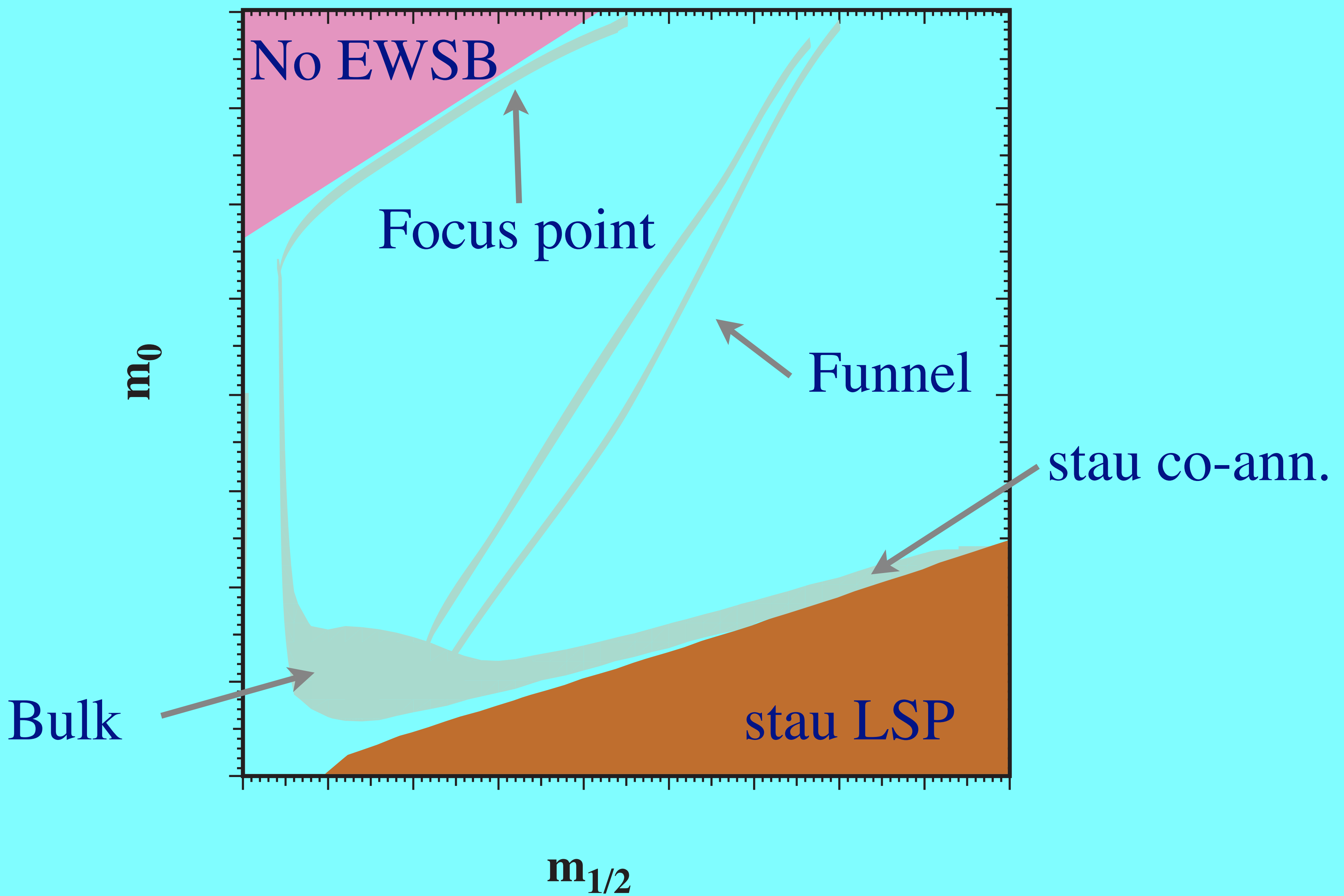
predict μ, B

mSugra Conditions

- Gaugino masses: $m_{3/2} = m_0$
- Bilinear term: $B_0 = A_0 - m_0$

predict μ, $\tan\beta$

Typical Regions



Direct Detection

- Eastic scattering cross sections for χ p

- Dominant contribution to spin-independent scattering

$$\mathcal{L} = \alpha_{3i}\bar{\chi}\chi\bar{q}_i q_i,$$

Through light squark exchange

– Dominant for binos

Through Higgs exchange

– Requires some Higgsino component

Uncertainties from hadronic matrix elements

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

The strangeness contribution to the proton mass

$$y = \frac{2B_s}{B_u + B_d} = \frac{(m_u + m_d)\langle p|s\bar{s}|p\rangle}{\Sigma}$$

$$= 1 - \frac{\sigma_0}{\Sigma}$$

$\sigma_0 = 36 \pm 7$ MeV

Gasser, Leutwyler, Sanio
Knecht

For $\Sigma = 45$ MeV, $y = 0.2$

$$f_{T_u} = 0.020 \qquad f_{T_d} = 0.026 \qquad f_{T_s} = 0.117$$

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For $\Sigma = 64$ MeV, $y = 0.44$

$$f_{T_u} = 0.027 \qquad f_{T_d} = 0.039 \qquad f_{T_s} = 0.363$$

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For $\Sigma = 64$ MeV, $y = 0.44$

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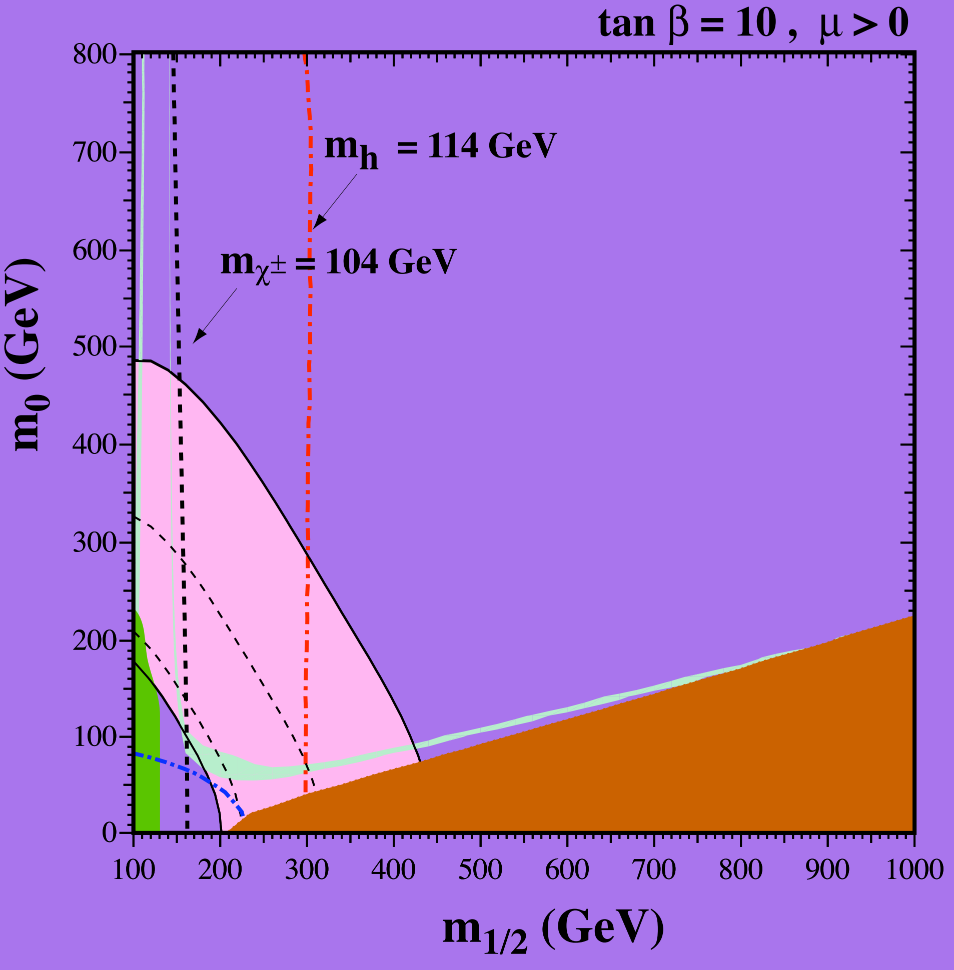
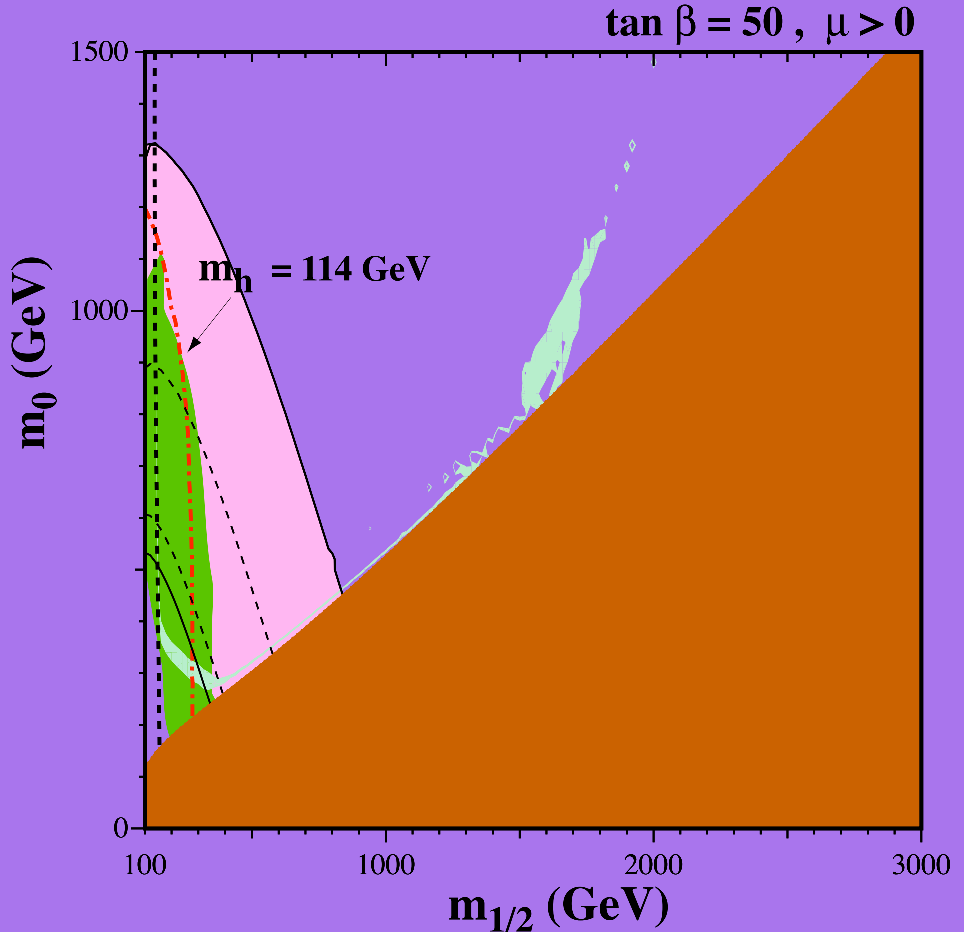
For $\Sigma = 36$ MeV, $y = 0$

$$f_{T_u} = 0.016 \qquad f_{T_d} = 0.020 \qquad f_{T_s} = 0.$$

CMSSM



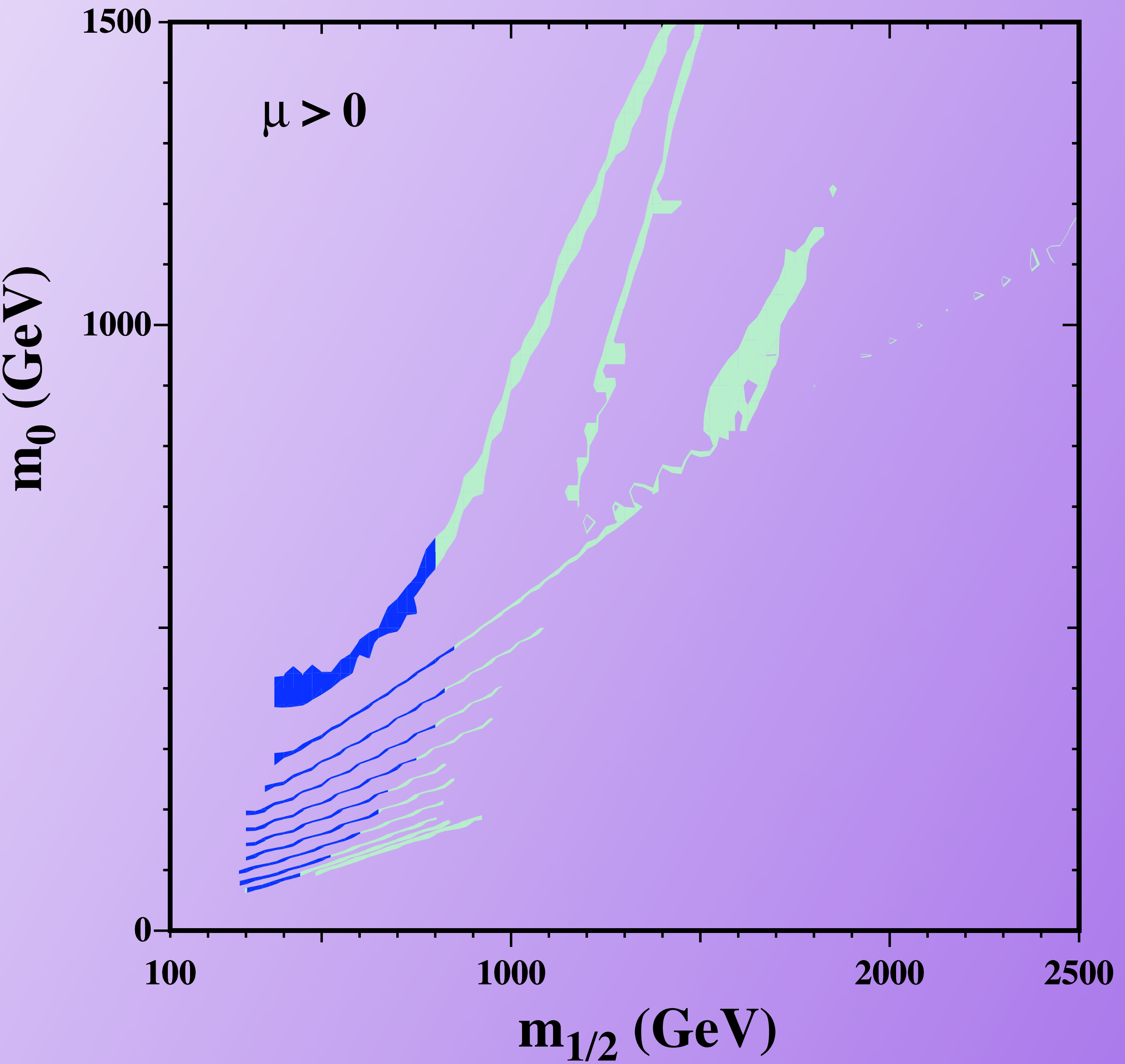
tan β = 10 , μ > 0
m_h = 114 GeV
m_χ± = 104 GeV
m_0 (GeV)
m_1/2 (GeV)
0
100
200
300
400
500
600
700
800
900
1000



tan β = 50 , μ > 0
m_h = 114 GeV
m_0 (GeV)
m_1/2 (GeV)
0
1000
1500
100
2000
3000

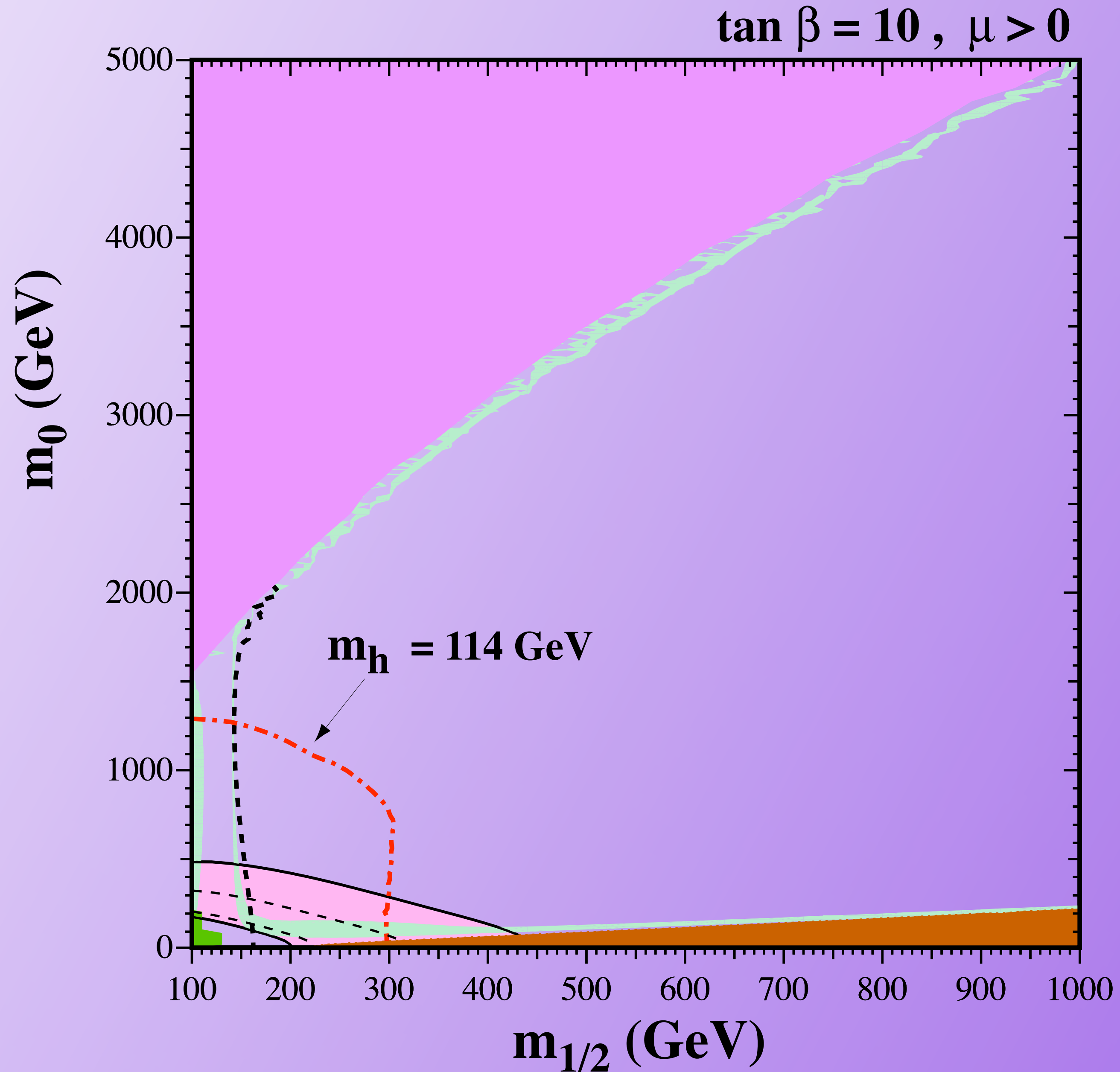
EOSS

Foliation in tan β



Focus Point Region

As m_0 gets very large, RGE's force μ to 0, allowing neutralino to become Higgsino like with an acceptable relic density.



Feng Matchev Moroi Wilczek

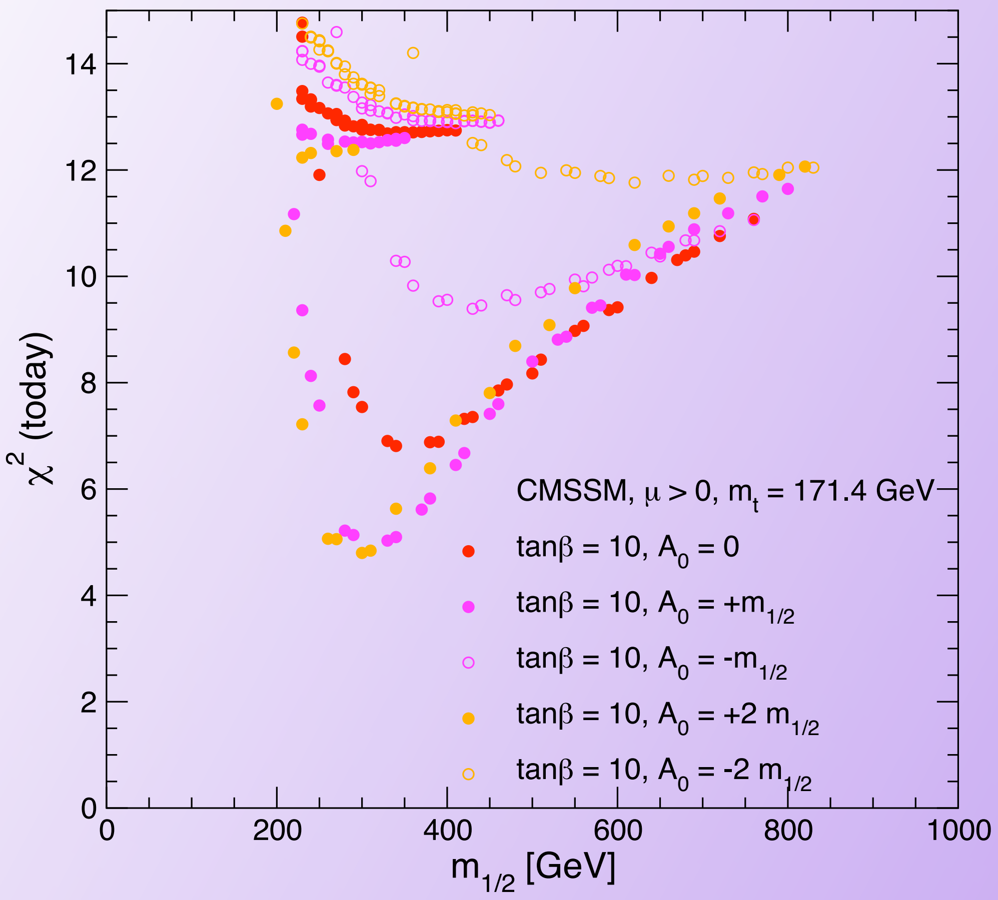
Indirect Sensitivities

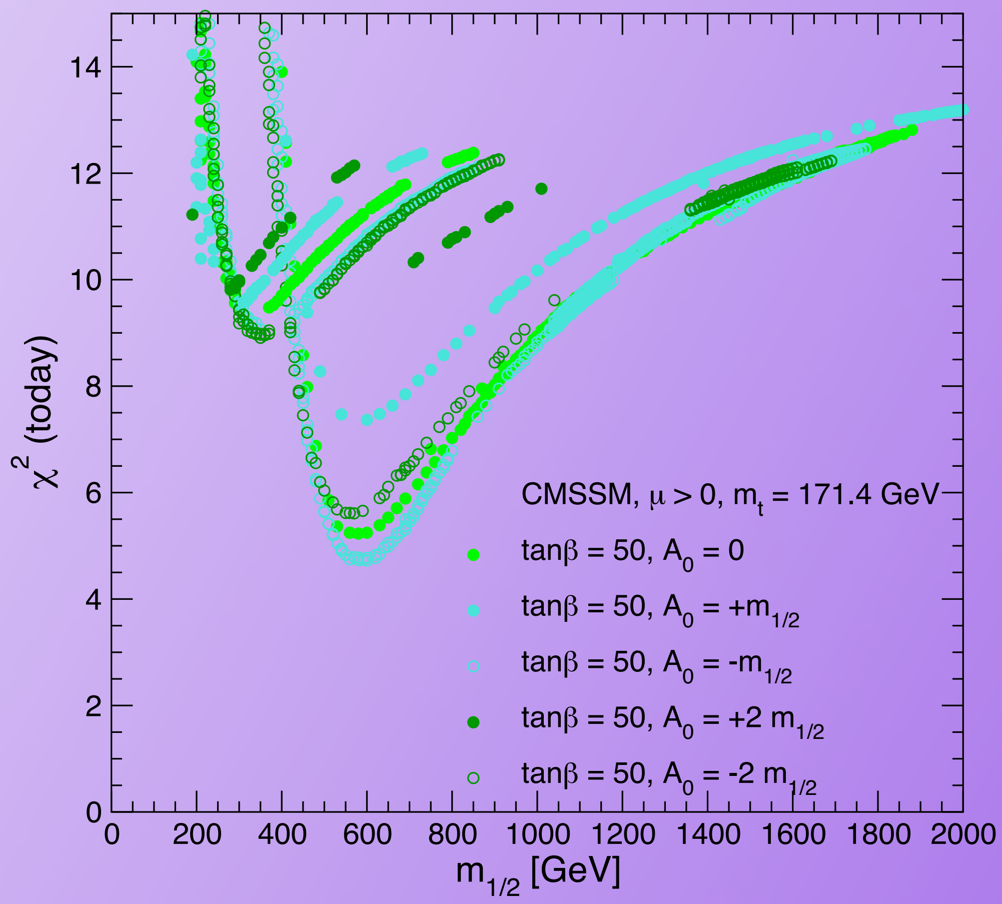
- M_W
- $\sin^2\theta$
- Γ_Z
- $(g-2)_\mu$
- $BR(b \to s\gamma)$
- $BR(B_u \to \tau\nu_\tau)$
- ΔM_{B_s}
- M_h
- $BR(B_s \to \mu^+\mu^-)$

$$\chi^2 \equiv \sum_{n=1}^{4} \left(\frac{R_n^{\mathrm{exp}} - R_n^{\mathrm{theo}}}{\sigma_n} \right)^2 + \chi^2_{M_h}$$

Ellis, Heinemeyer, Olive, Weber, Weiglein

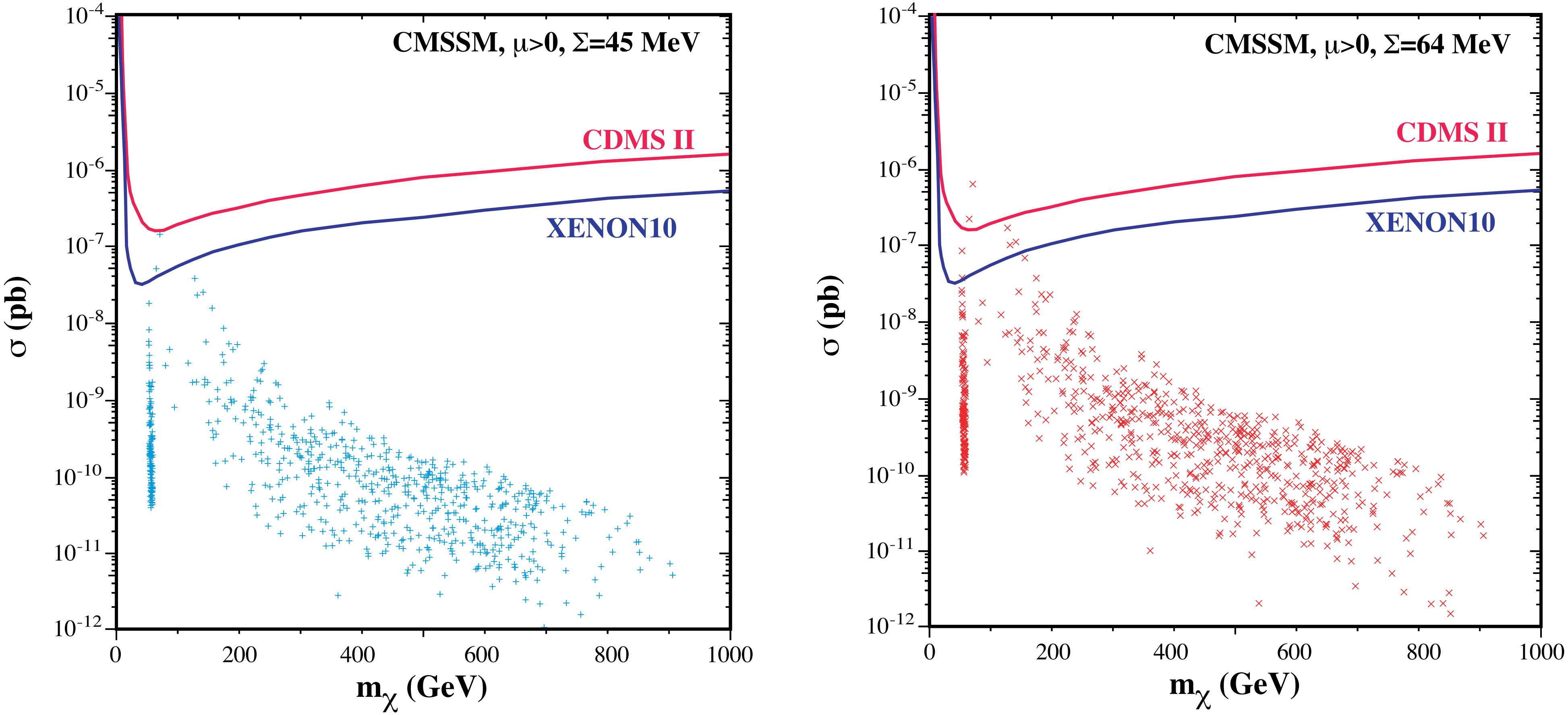
Indirect Sensitivities to CMSSM models





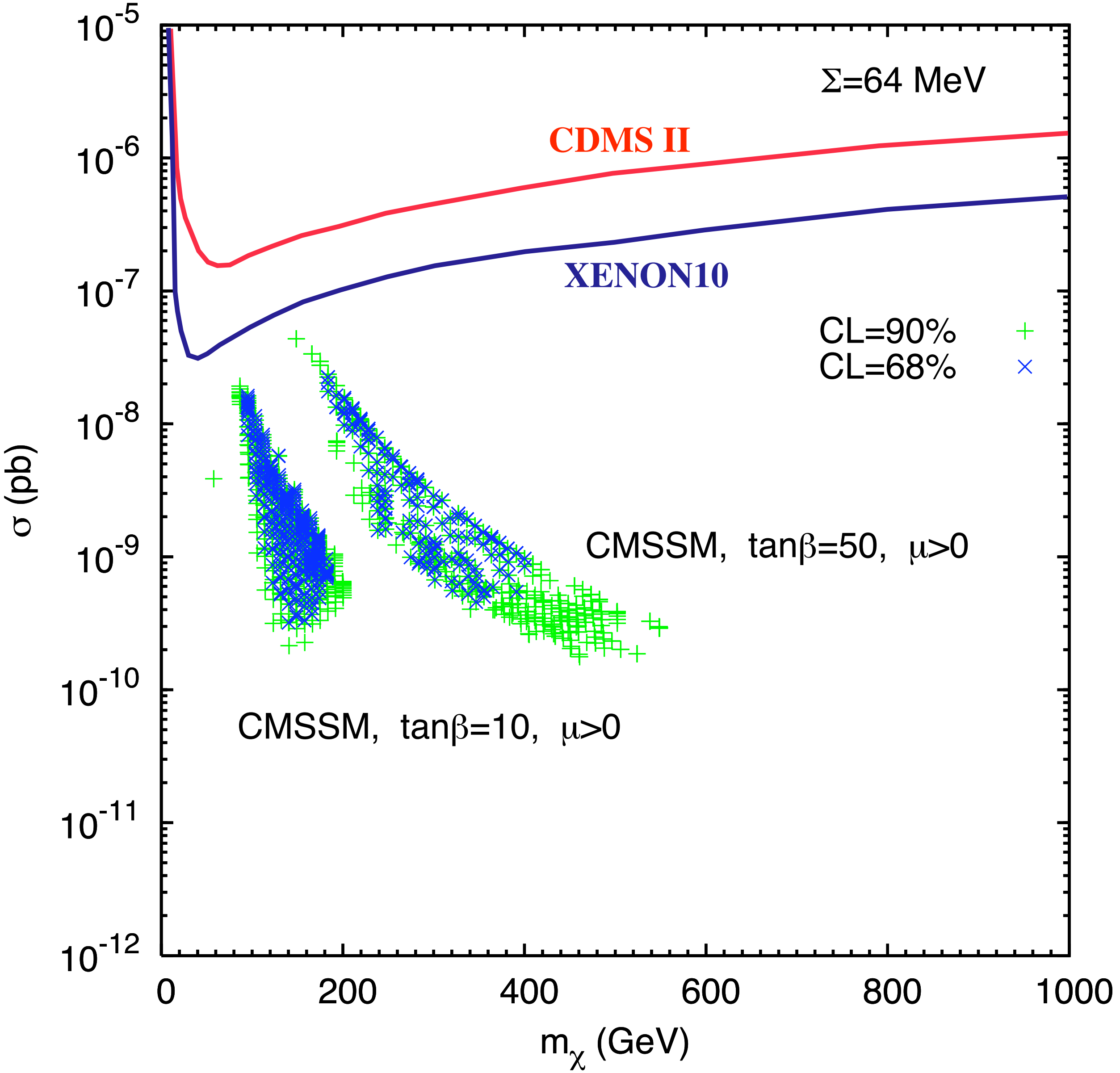
EHOWW

Direct Detection in the CMSSM



Ellis, Olive, Santoso, Spanos

Direct Detection in regions of lowest χ^2



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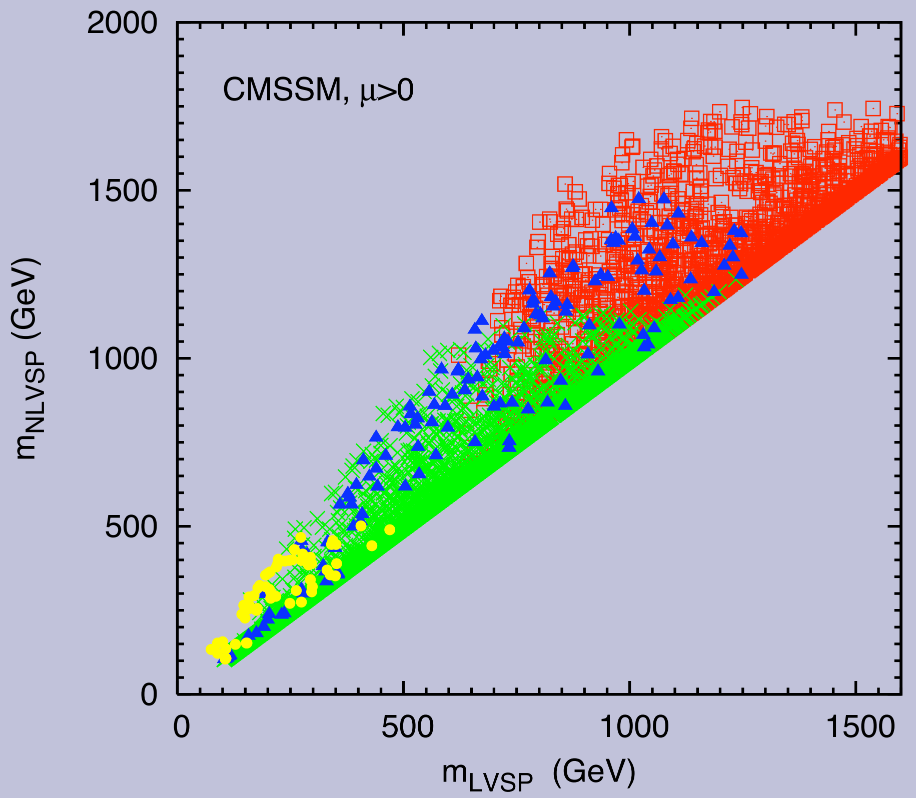
Visible Particle Masses



Phenomenologically acceptable points

X LHC visible points
cf Baer etal

Cosmologically acceptable points

$\sigma_p > 10^{-8}$ pb

Ellis, KAO, Santoso, Spanos

Sub-GUT models

Why assume that the supersymmetry breaking scale is M_{GUT} ?

Ellis, Olive, Sandick

Sub-GUT models

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Flavor-blind supersymmetry breaking → universality

Ellis, Olive, Sandick

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but at what scale?

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Gauge coupling unification maintained (at the GUT scale)

Ellis, Olive, Sandick

Sub-GUT models

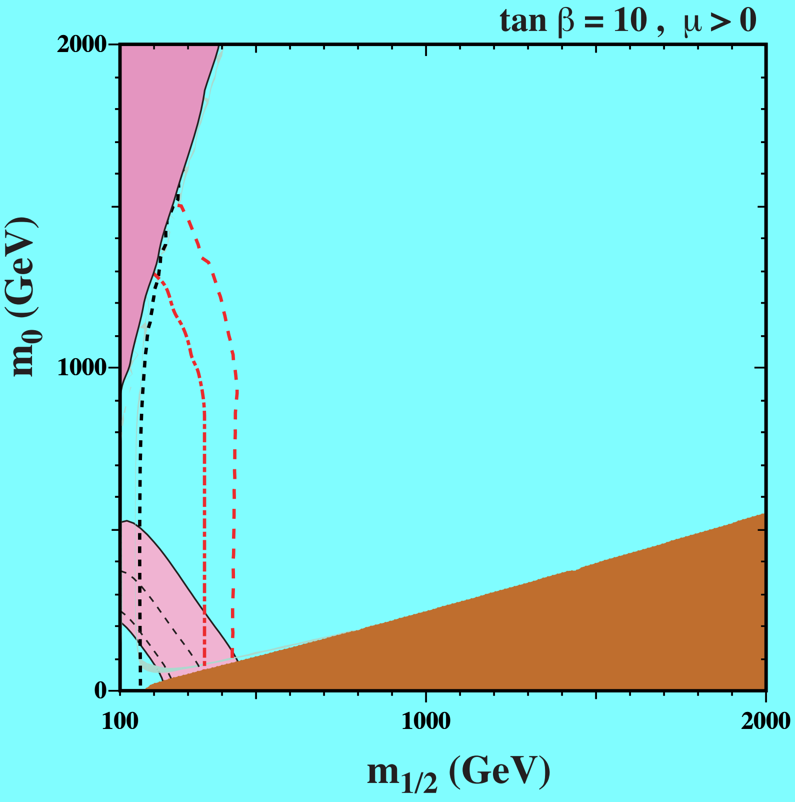
Why assume that the supersymmetry breaking scale is M_{GUT} ?

Flavor-blind supersymmetry breaking → universality
but at what scale?

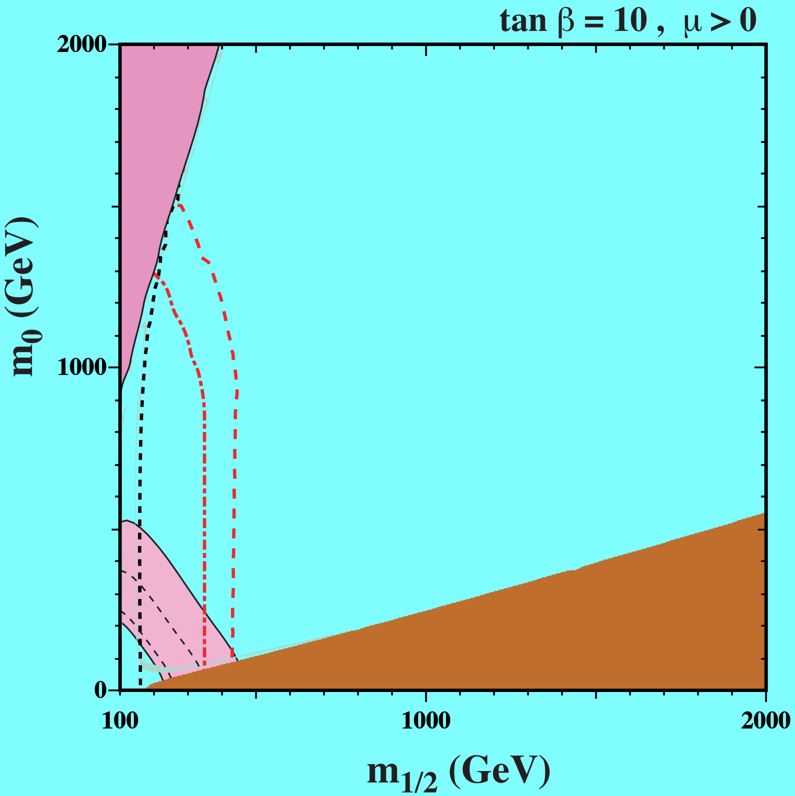
Gauge coupling unification maintained (at the GUT scale)

Gaugino and scalar masses unified at some scale $M_{in} < M_{GUT}$

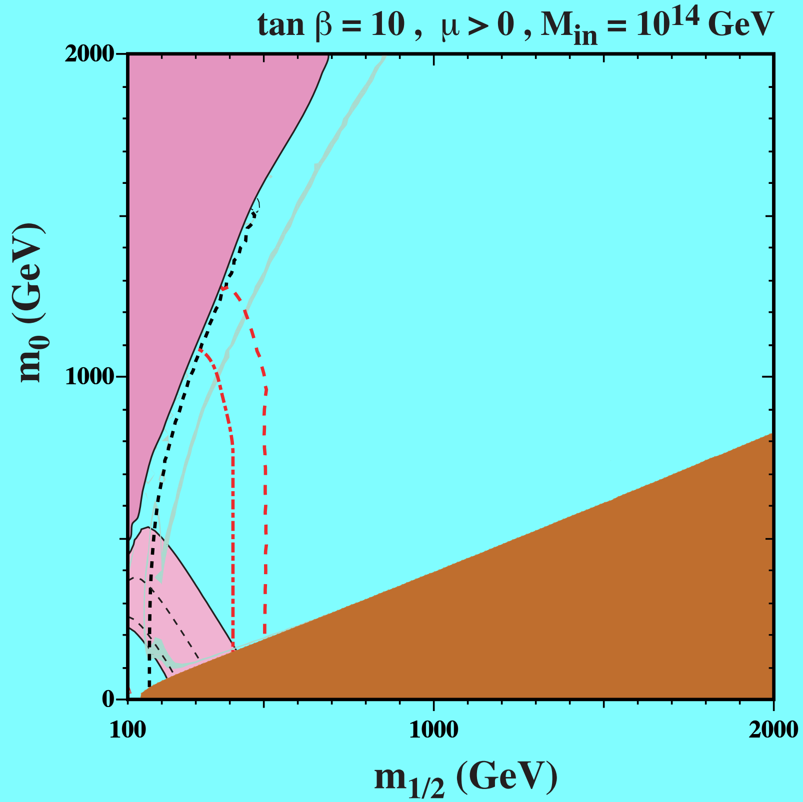
Ellis, Olive, Sandick



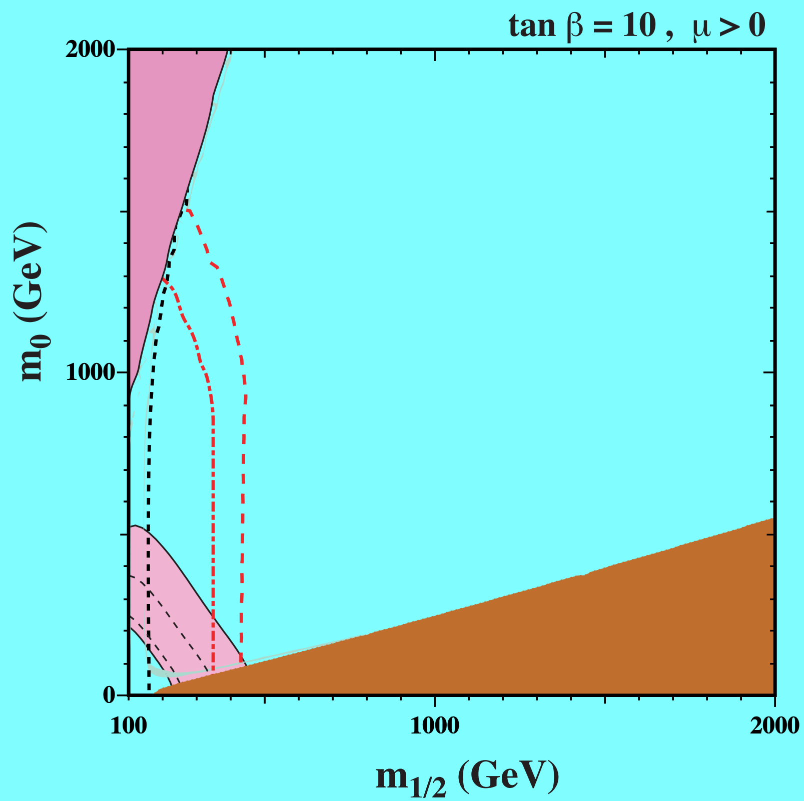
tan β = 10 , μ > 0
2000
1000
0
m0 (GeV)
100
1000
2000
m1/2 (GeV)



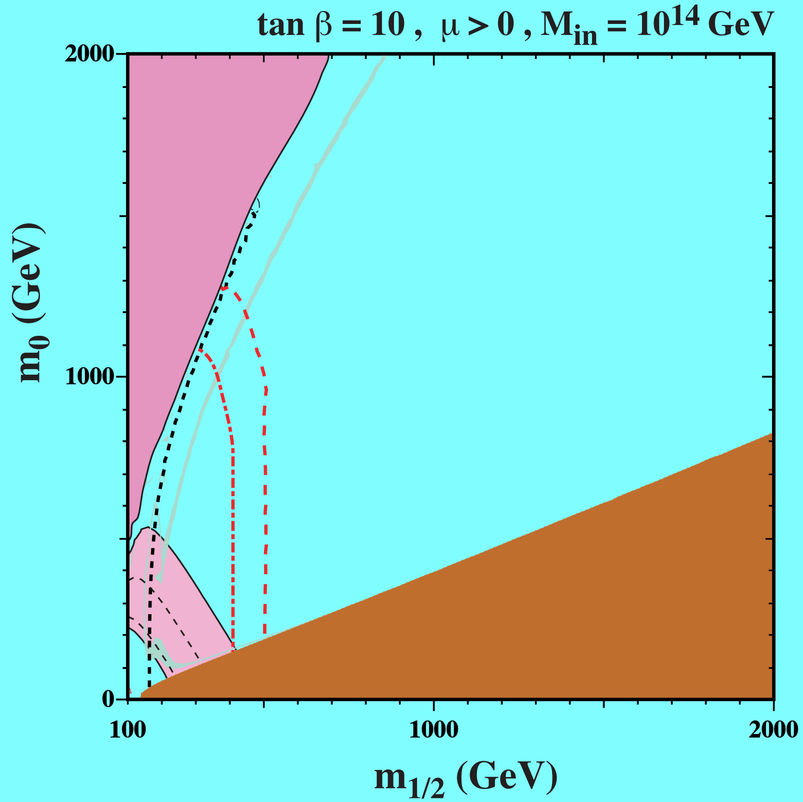
tan β = 10 , μ > 0
2000
1000
0
m0 (GeV)
100
1000
2000
m1/2 (GeV)



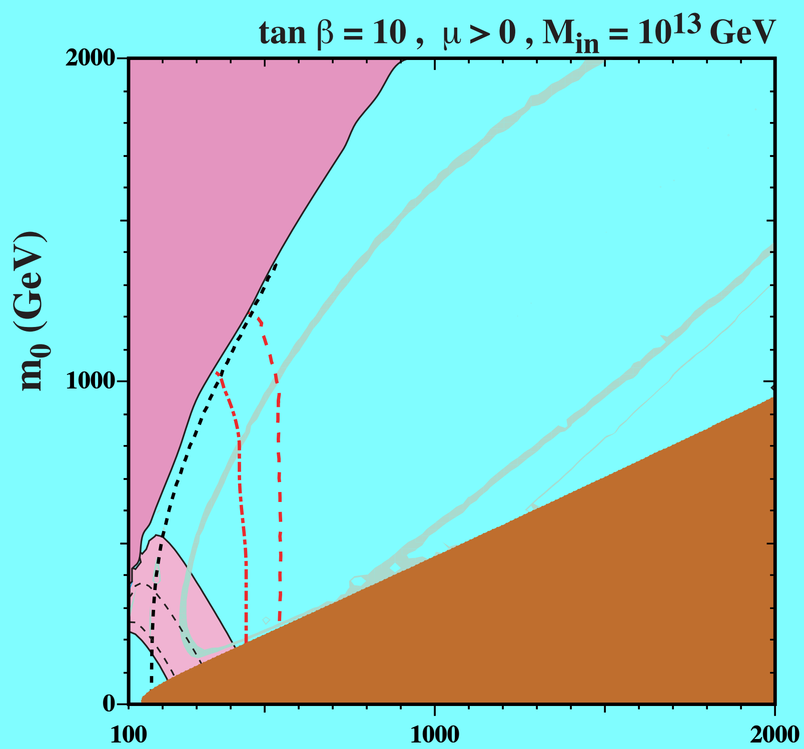
tan β = 10 , μ > 0 , Min = 10^14 GeV
2000
1000
0
m0 (GeV)
100
1000
2000
m1/2 (GeV)



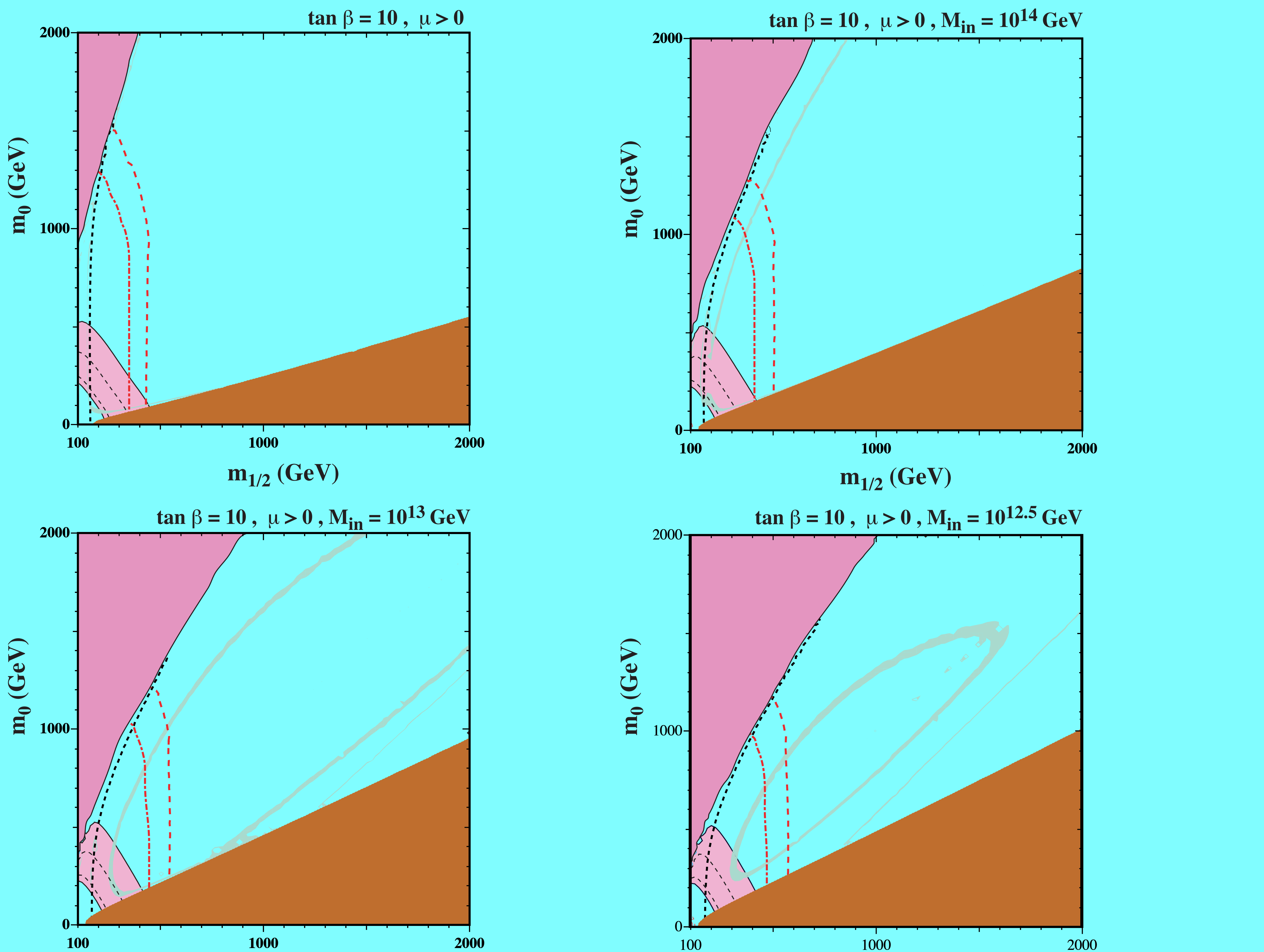
tan β = 10 , μ > 0
m0 (GeV)
m1/2 (GeV)
0
1000
2000
100
1000
2000



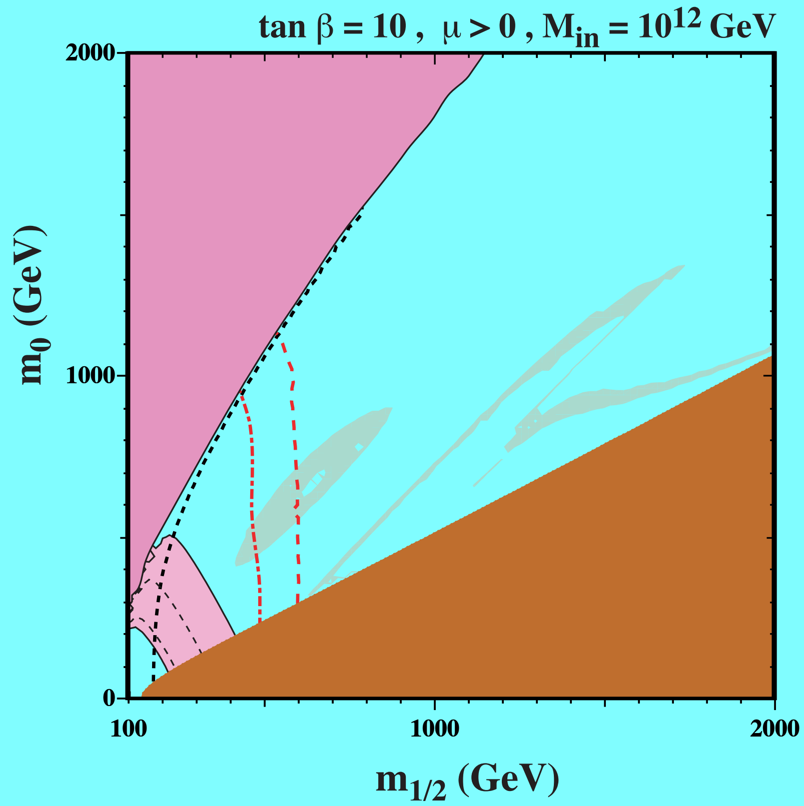
tan β = 10 , μ > 0 , Min = 10^14 GeV
m0 (GeV)
m1/2 (GeV)
0
1000
2000
100
1000
2000



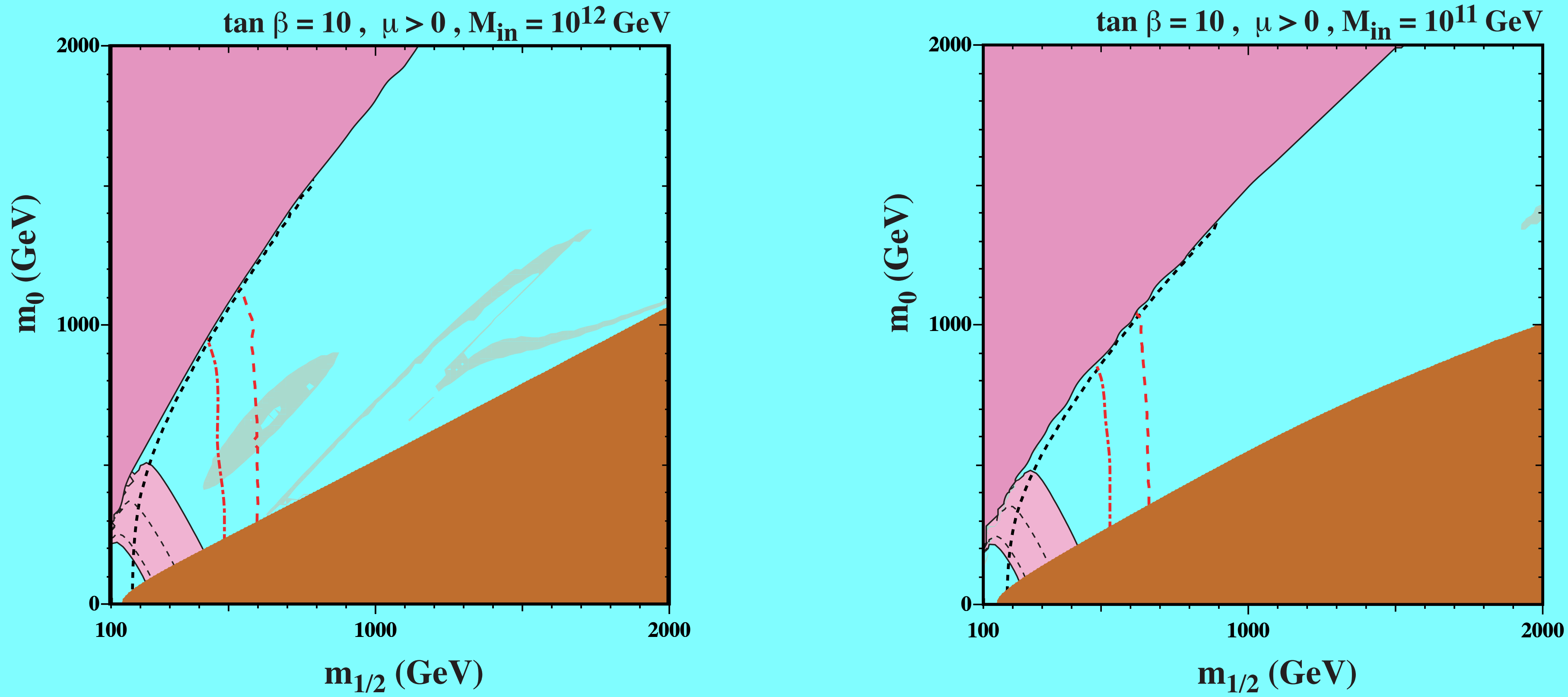
tan β = 10 , μ > 0 , Min = 10^13 GeV
m0 (GeV)
0
1000
2000
100
1000
2000



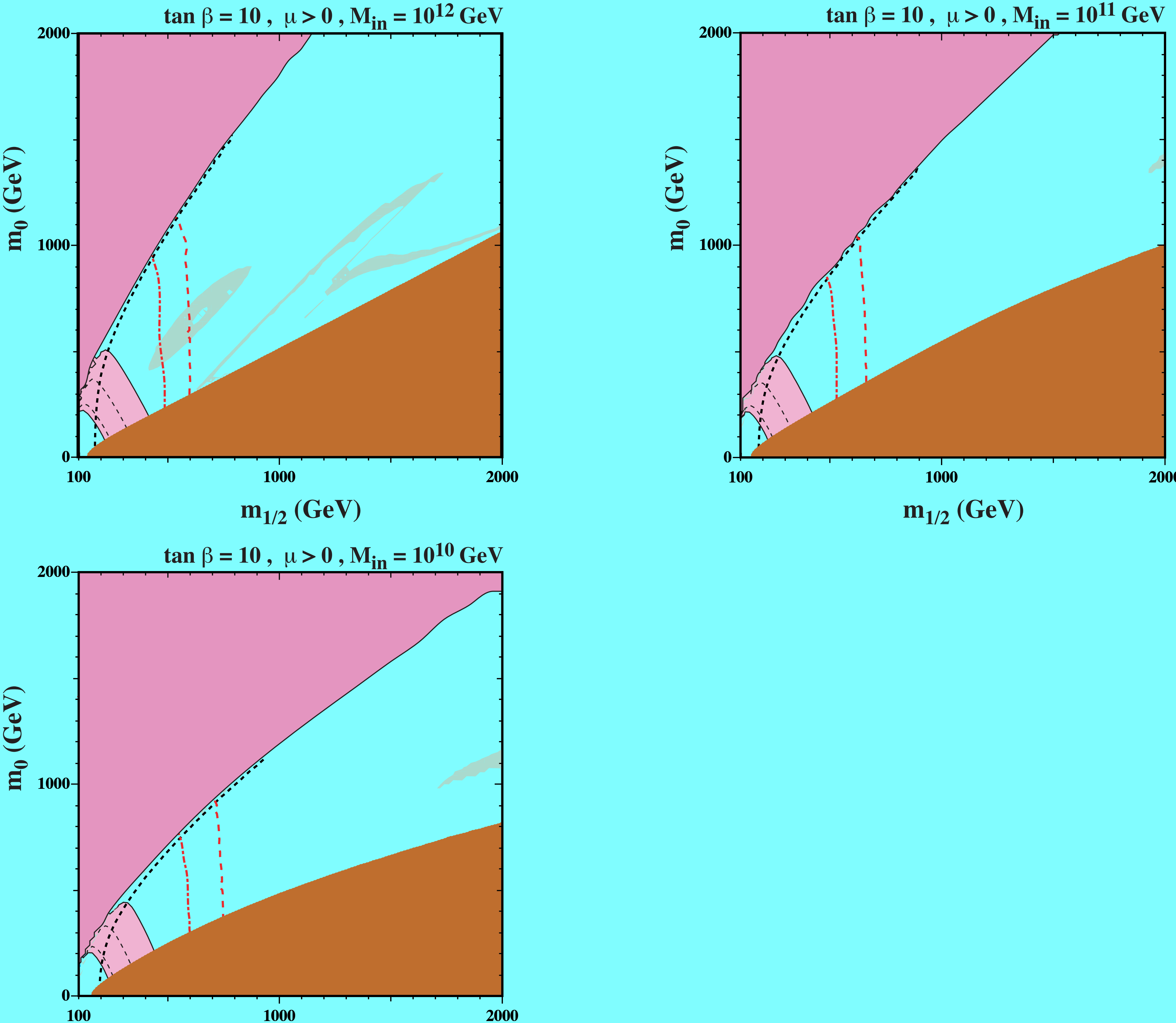
$\tan\beta = 10, \mu > 0$
$\tan\beta = 10, \mu > 0, M_{in} = 10^{14}$ GeV
$\tan\beta = 10, \mu > 0, M_{in} = 10^{13}$ GeV
$\tan\beta = 10, \mu > 0, M_{in} = 10^{12.5}$ GeV
m_0 (GeV)
$m_{1/2}$ (GeV)
0
1000
2000
100



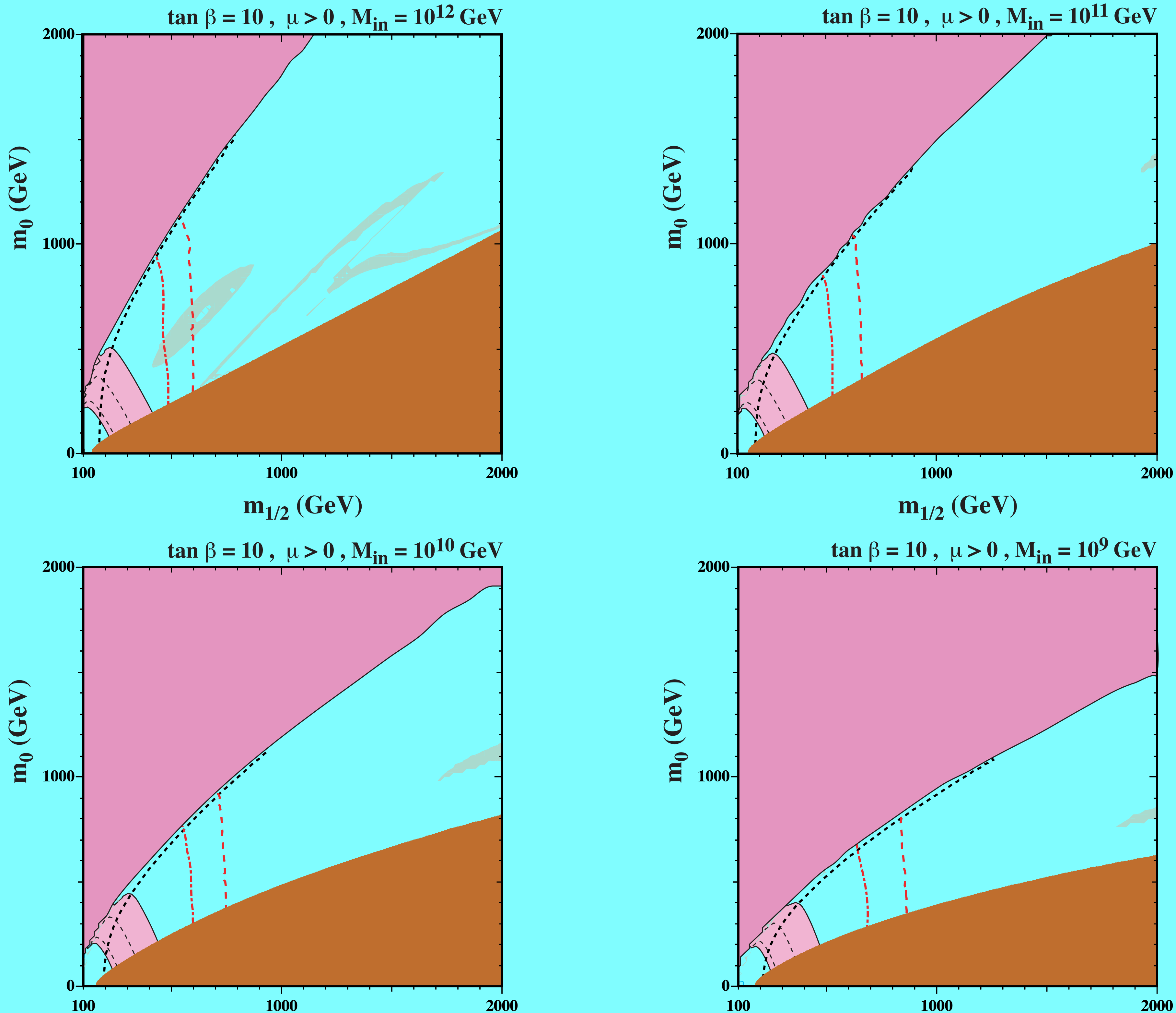
tan β = 10 , μ > 0 , M$_{in}$ = 10^{12} GeV
2000
1000
0
100
1000
2000
m$_0$ (GeV)
m$_{1/2}$ (GeV)



tan β = 10 , μ > 0 , M_in = 10^12 GeV
m_0 (GeV)
m_1/2 (GeV)
2000
1000
0
100
1000
2000
tan β = 10 , μ > 0 , M_in = 10^11 GeV
m_0 (GeV)
m_1/2 (GeV)
2000
1000
0
100
1000
2000



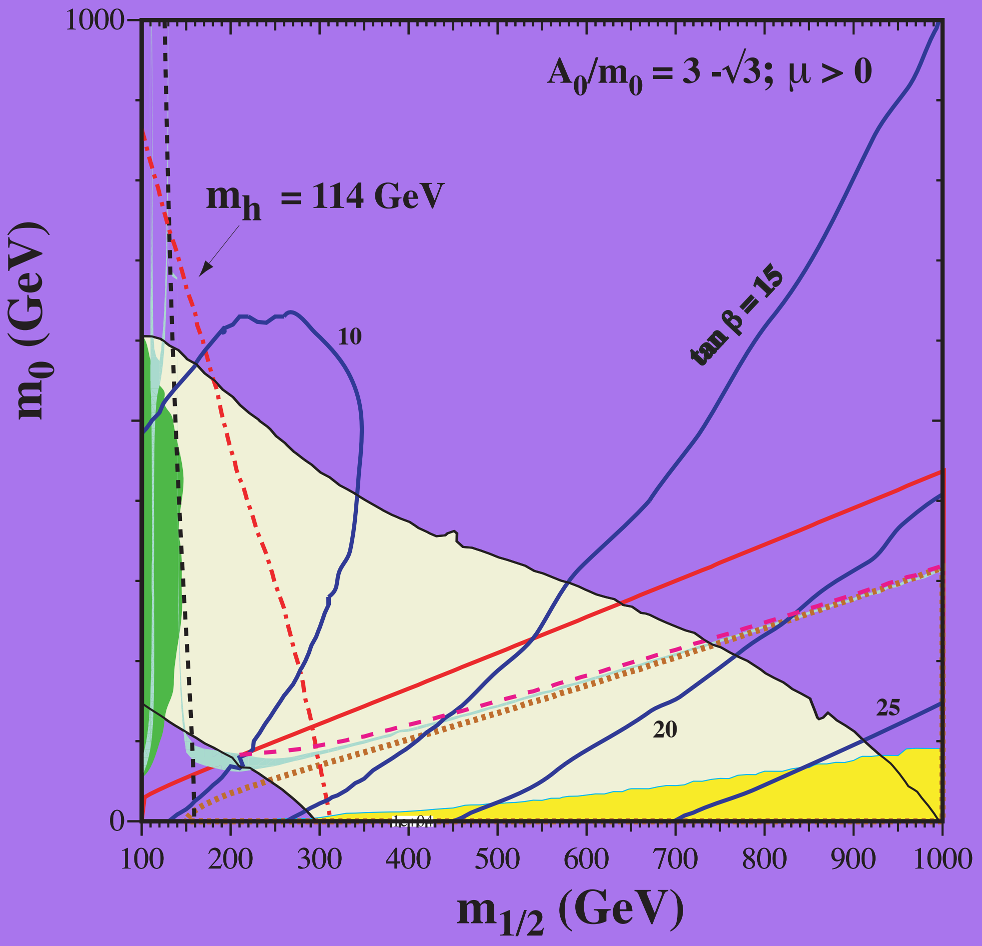
tan β = 10 , μ > 0 , M_in = 10^12 GeV
m_0 (GeV)
m_1/2 (GeV)
2000
1000
0
100
1000
2000
tan β = 10 , μ > 0 , M_in = 10^11 GeV
m_0 (GeV)
m_1/2 (GeV)
2000
1000
0
100
1000
2000
tan β = 10 , μ > 0 , M_in = 10^10 GeV
m_0 (GeV)
2000
1000
0
100
1000
2000

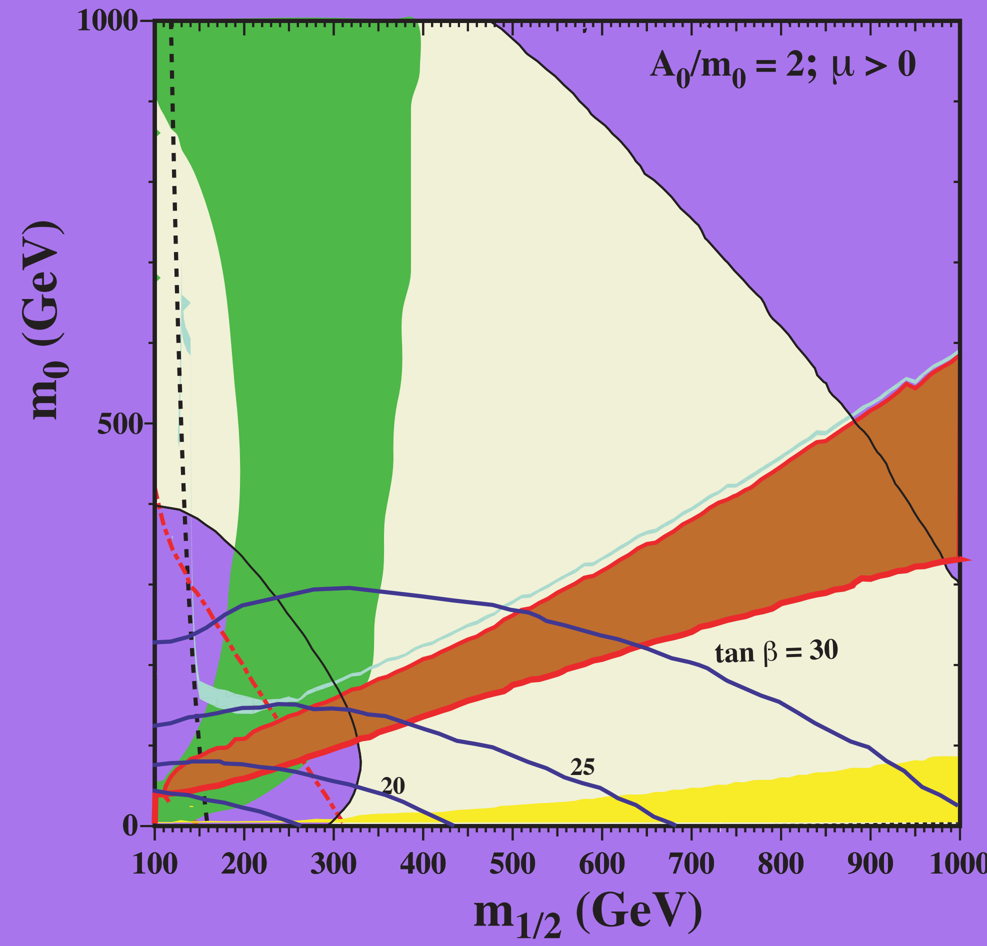


tan β = 10 , μ > 0 , M_in = 10^12 GeV
tan β = 10 , μ > 0 , M_in = 10^11 GeV
tan β = 10 , μ > 0 , M_in = 10^10 GeV
tan β = 10 , μ > 0 , M_in = 10^9 GeV
m_0 (GeV)
m_1/2 (GeV)
0
1000
2000
100

mSugra models

- $\tan\beta$ fixed by boundary conditions ($B_0 = A_0 - m_0$)
- ``planes'' determined by A_0/m_0
- Gravitino often the LSP ($m_{3/2} = m_0$)





The Very CMSSM (mSUGRA):

- Add $B_0 = A_0 - m_0$: Select tan β

Ellis, Olive, Santoso, Spanos

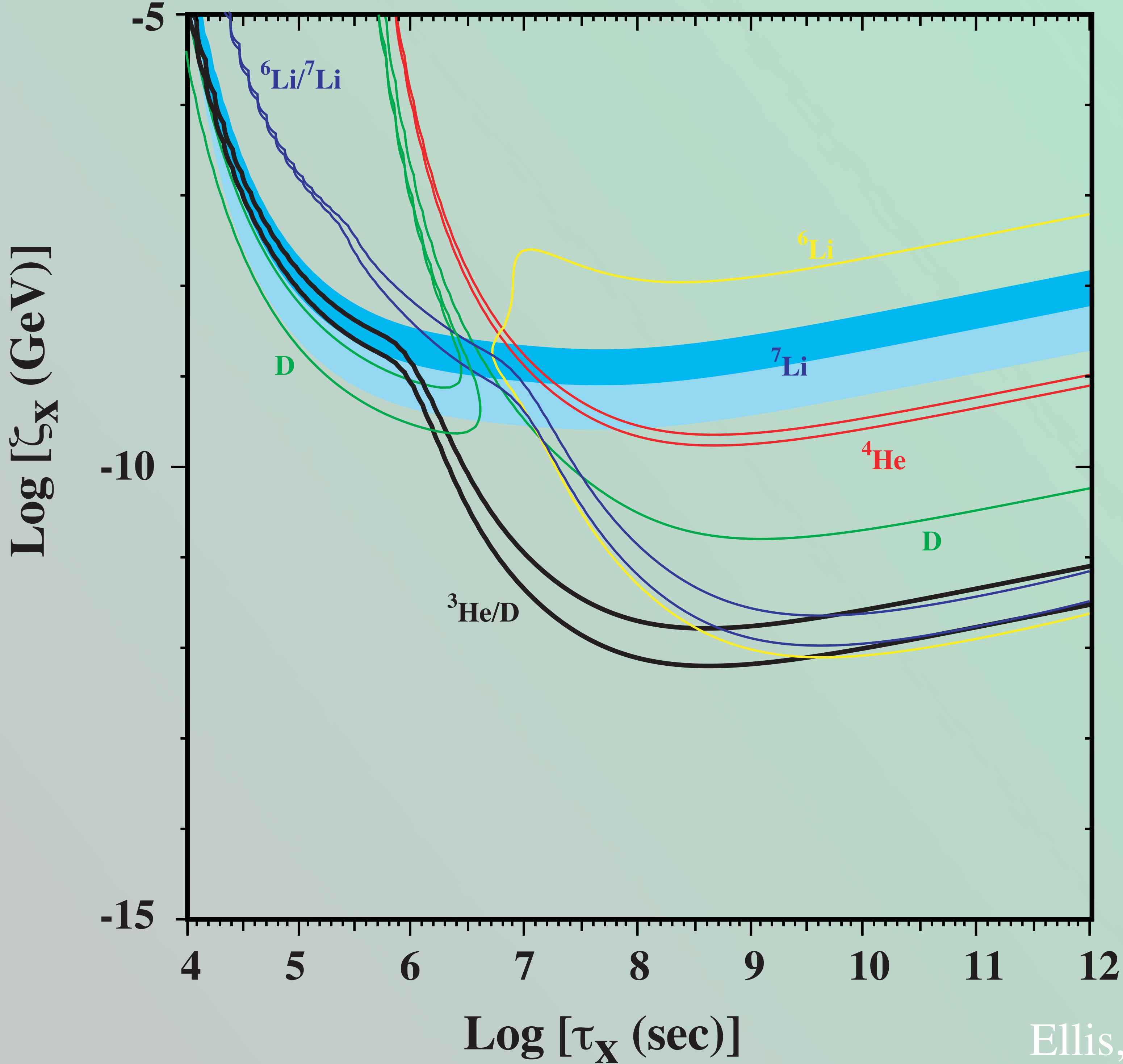
Limits on Unstable particles due to

Photo-Destruction and -Production of Nuclei

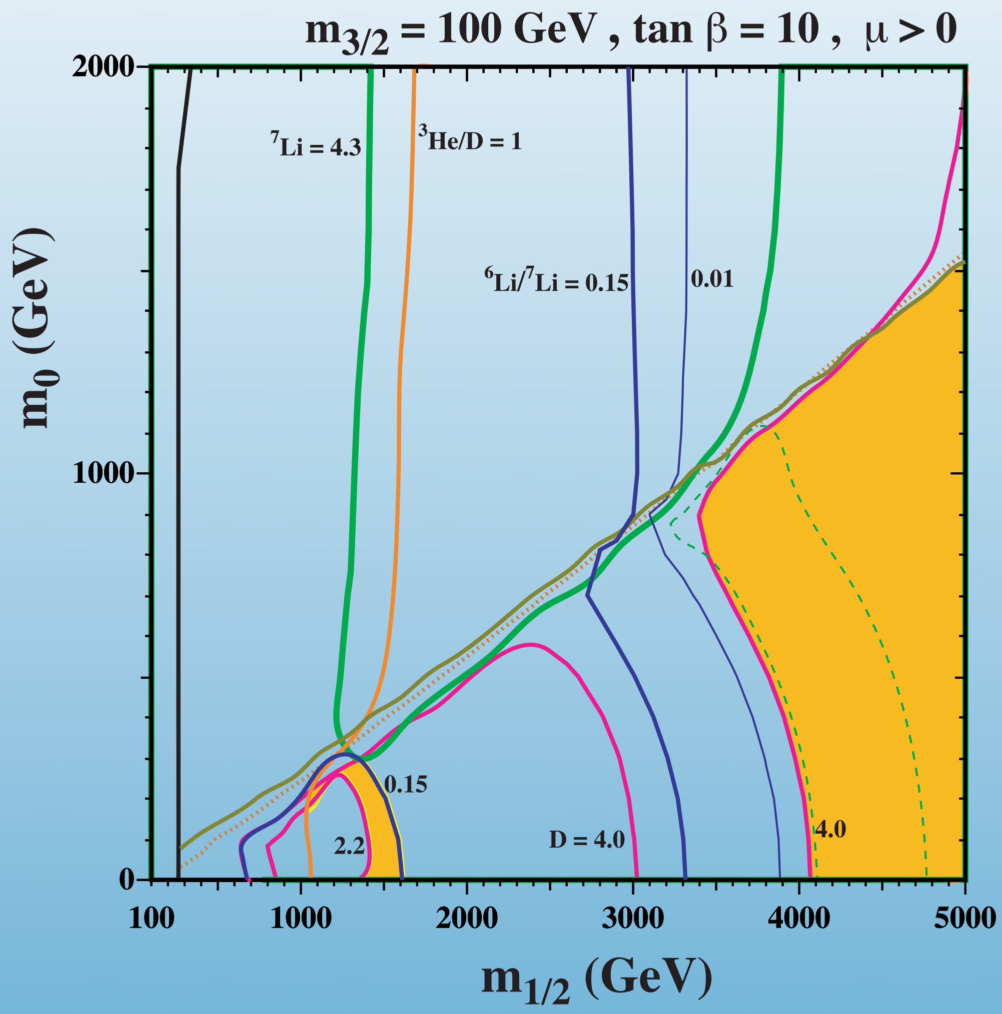
2 key parameters

$$\zeta_X \equiv \frac{n_X^0}{n_\gamma^0} M_X = r M_X = 2 r E_0, \quad \text{and} \quad \tau_X$$

Holtmann et al, Kawasaki et al, Kohri, Jedamzik, Steffan,....



Ellis, KAO, Vangioni



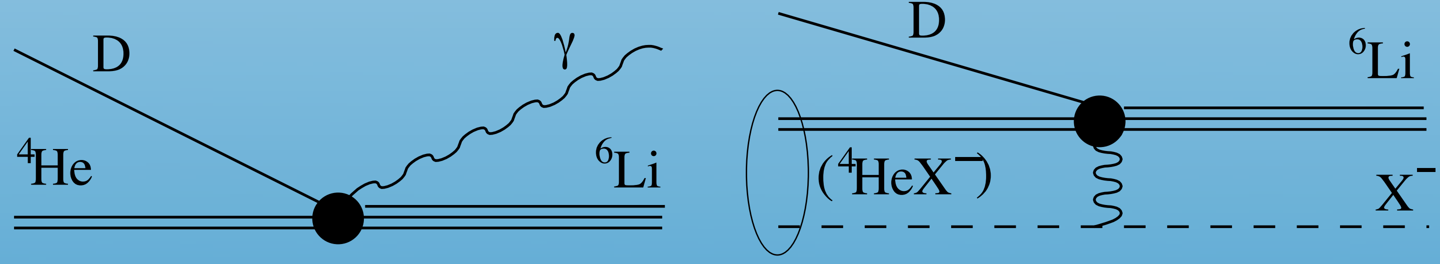
Cyburt, Ellis, Fields, KO, Spanos

Effects of Bound States

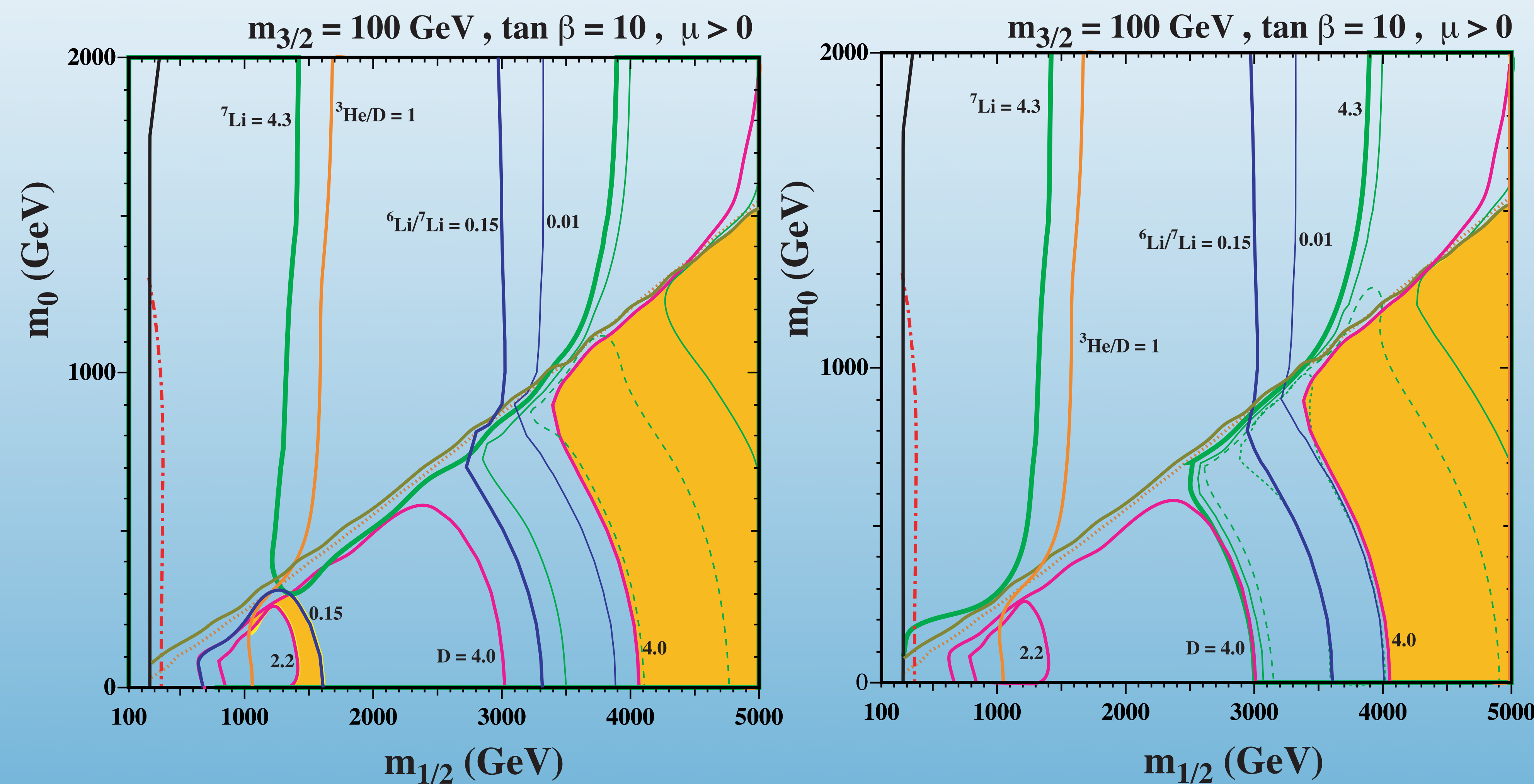
• In SUSY models with a $\tilde{\tau}$ NLSP, bound states form between ^{4}He and $\tilde{\tau}$

•The ^{4}He (D, γ) ^{6}Li reaction is normally highly suppressed (production of low energy γ)

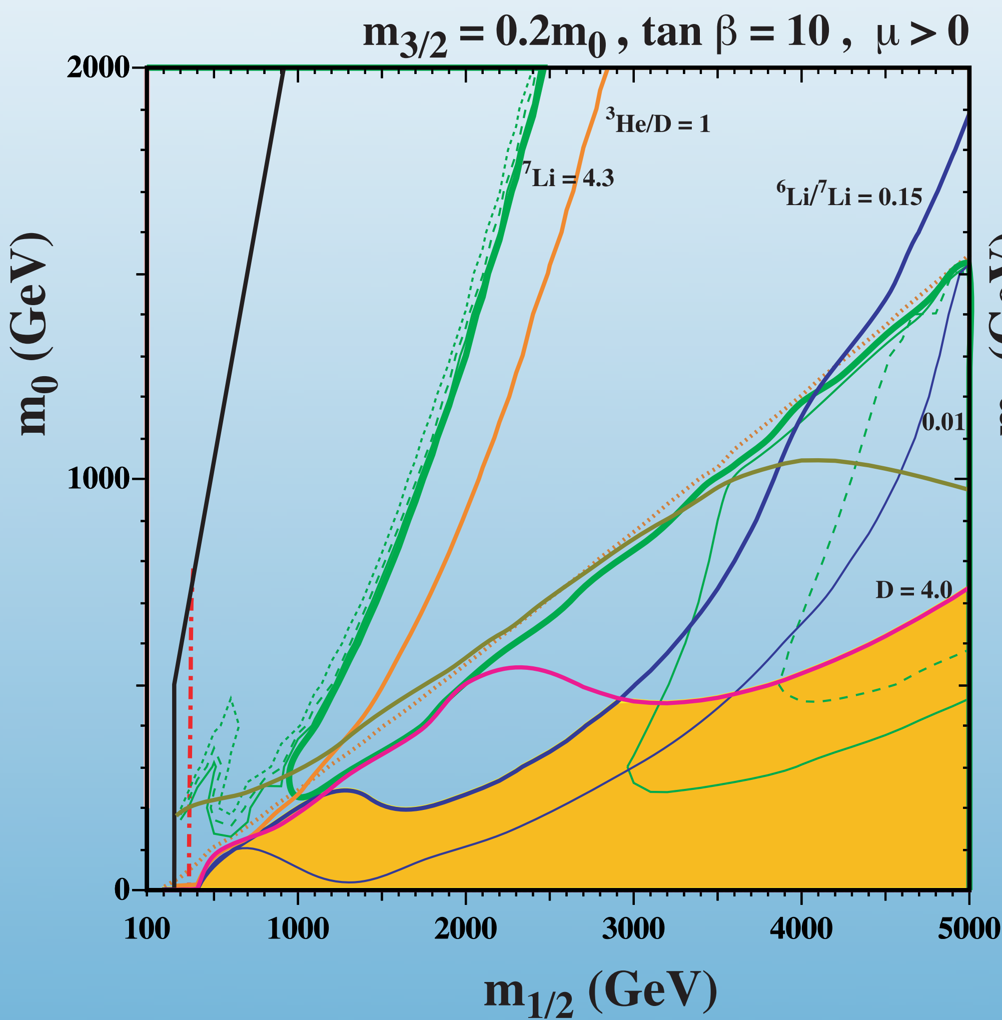
•Bound state reaction is not suppressed

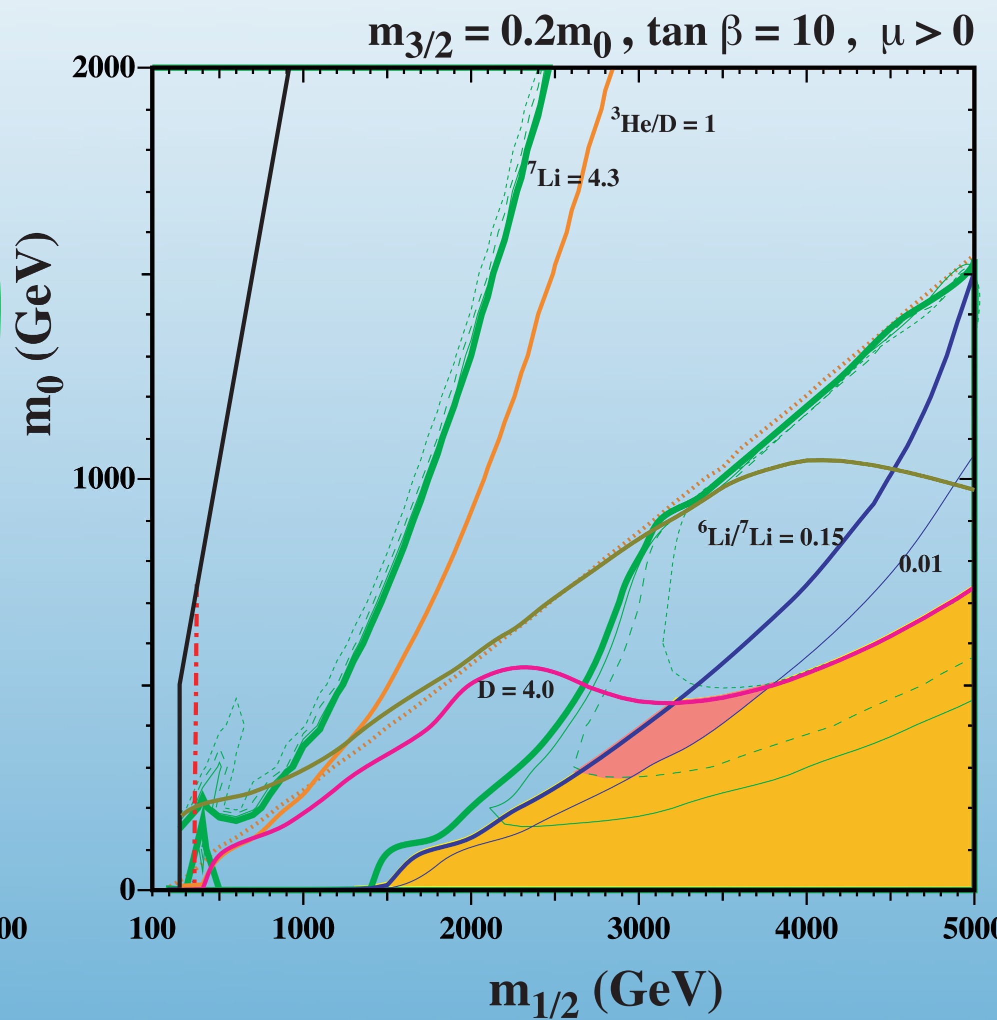


Pospelov

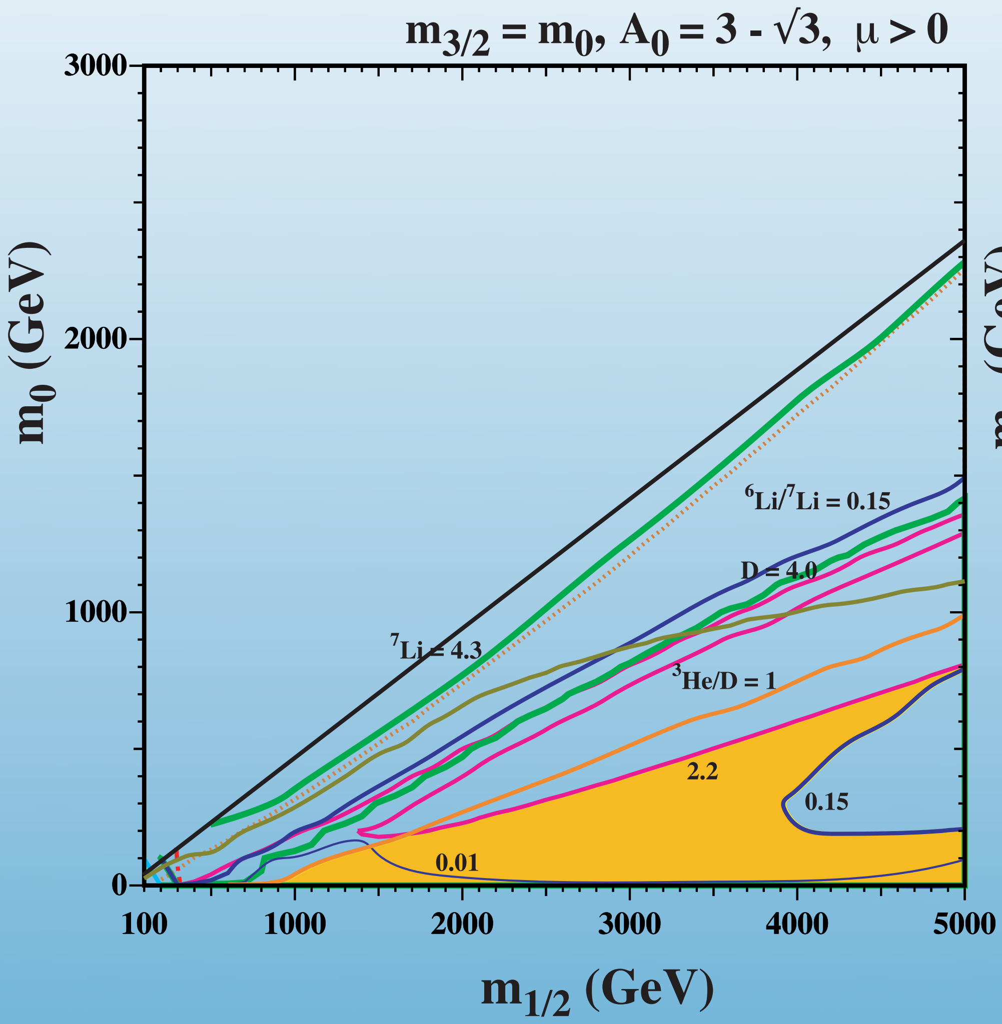


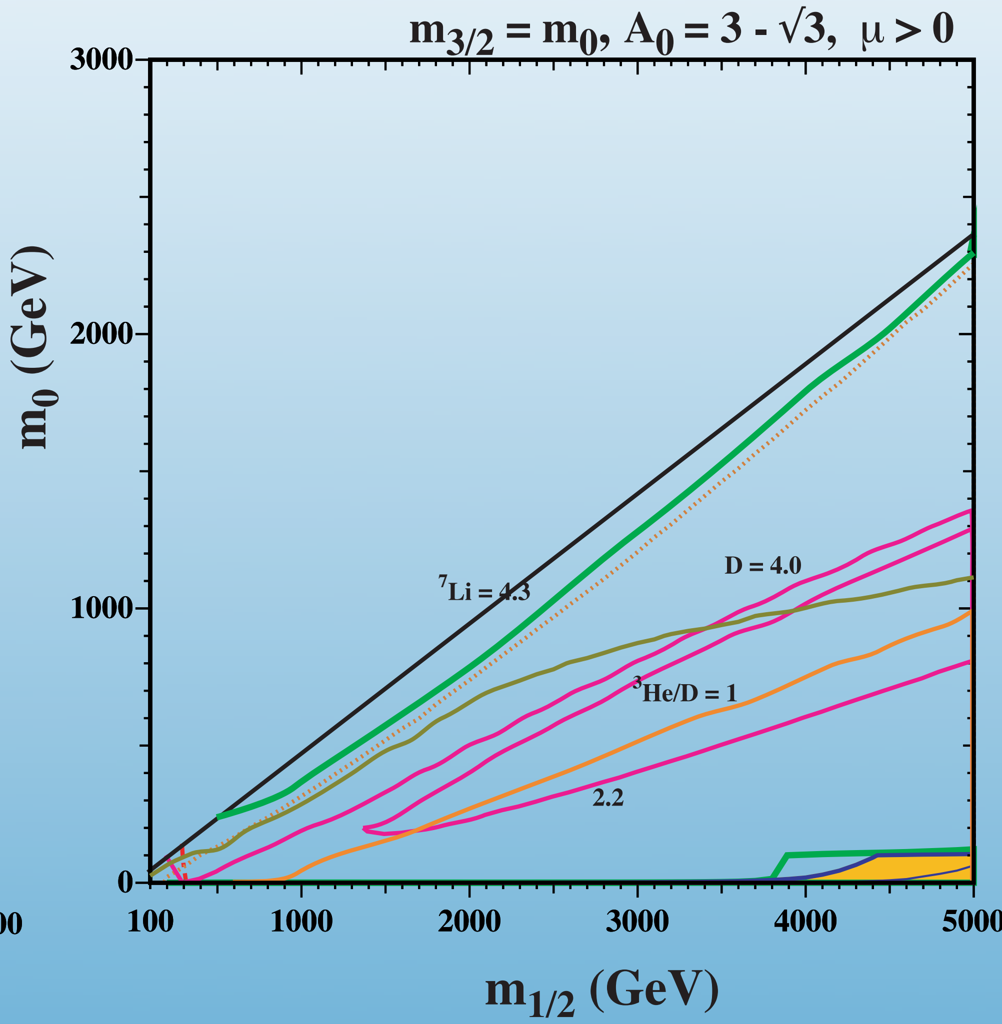
Cyburt, Ellis, Fields, KO, Spanos





Cyburt, Ellis, Fields, KO, Spanos



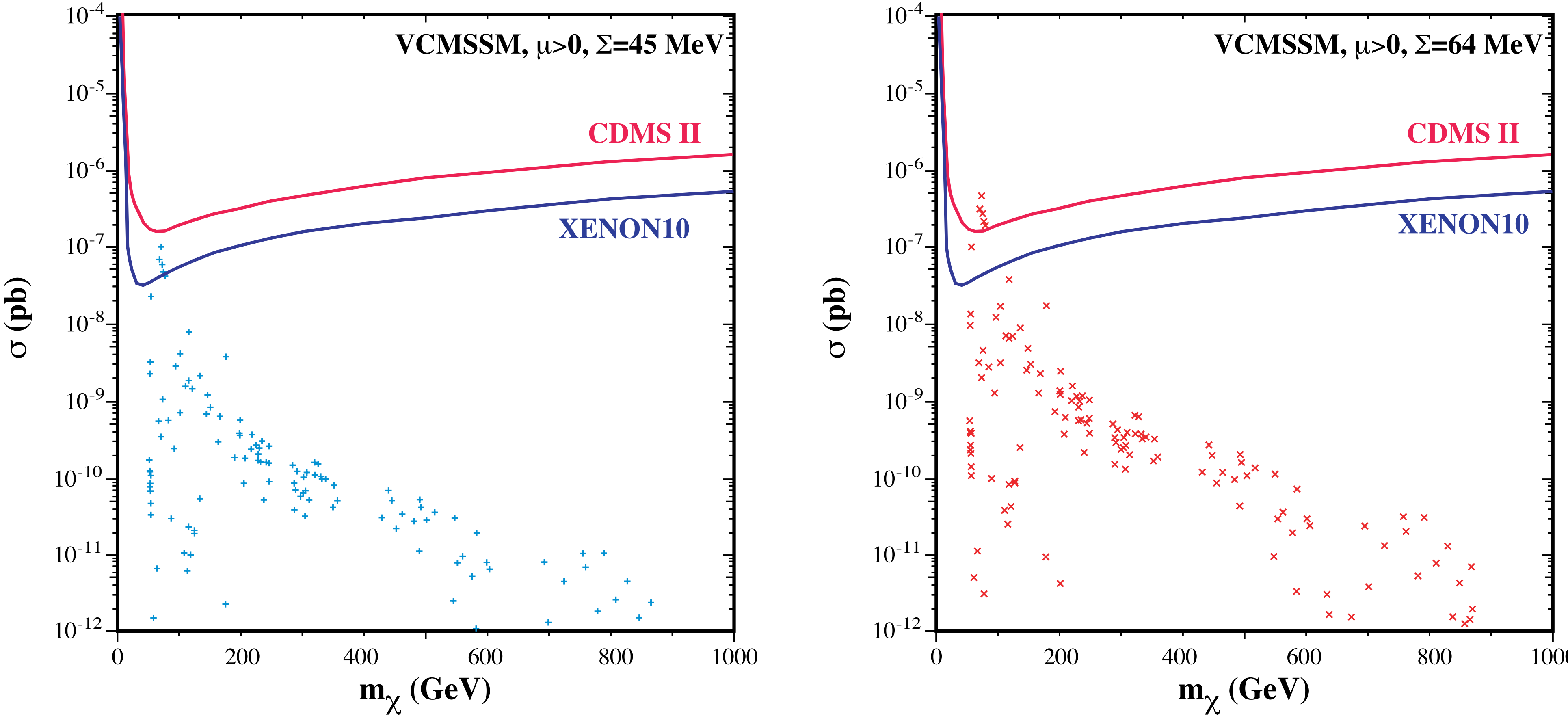


Cyburt, Ellis, Fields, KO, Spanos

mSugra models

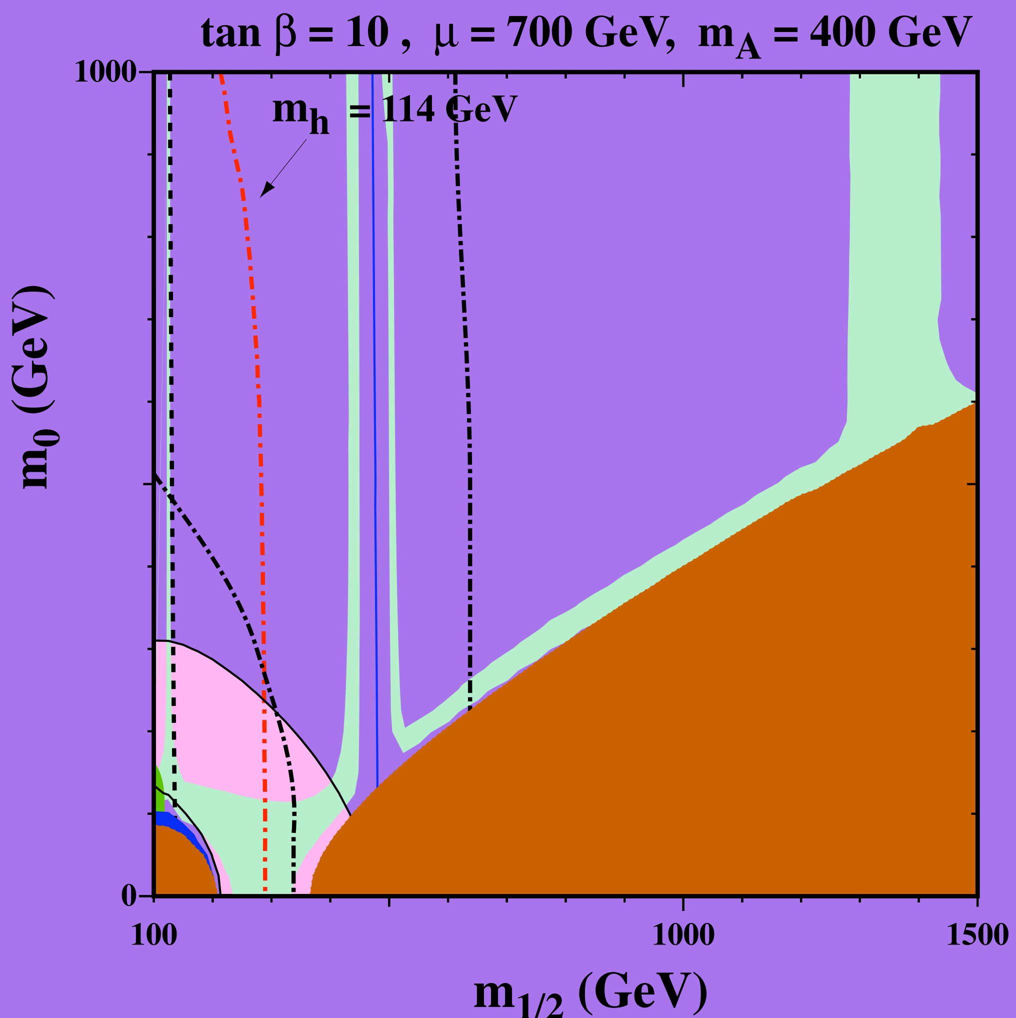
- tan β fixed by boundary conditions ($B_0 = A_0 - m_0$)
- ``planes'' determined by A_0/m_0
- Gravitino often the LSP ($m_{3/2} = m_0$)
- No Funnels
- No Focus Point

Direct Detection of NDM in the mSugra models



NUHM

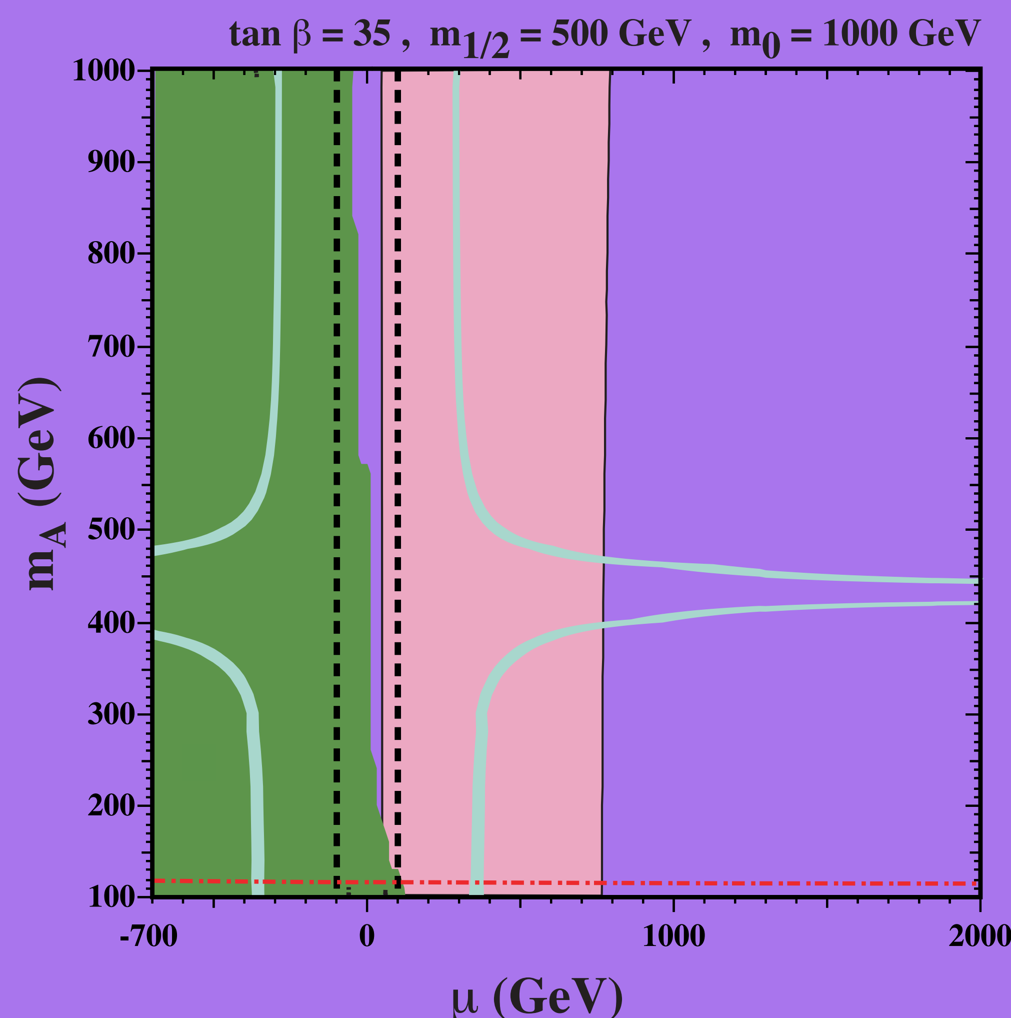
- Drop unification of scalar masses
- All Higgs soft masses, m_1 and m_2, to be chosen independently of m_0
- Allows μ and m_A to be free parameters



The $m_0 - m_{1/2}$ plane

+ CMSSM value

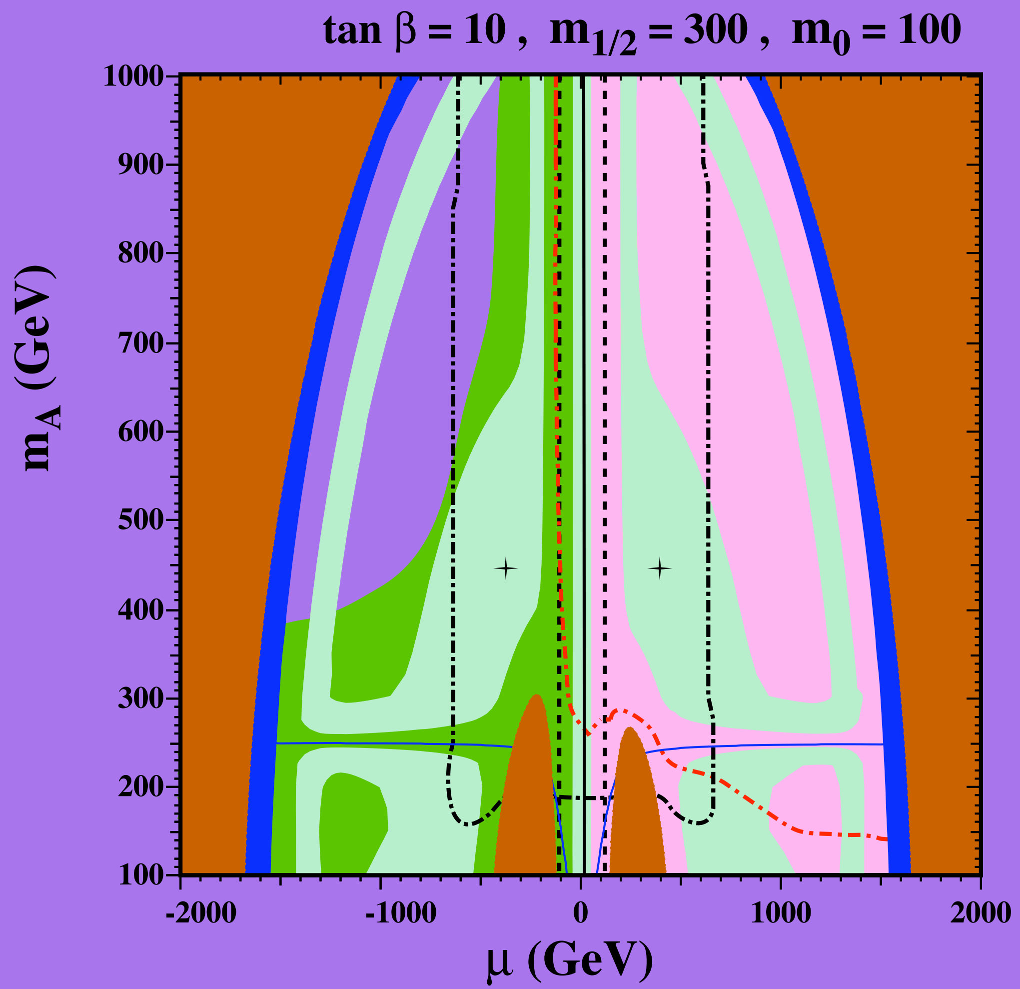
Ellis, Falk, Olive, Santoso

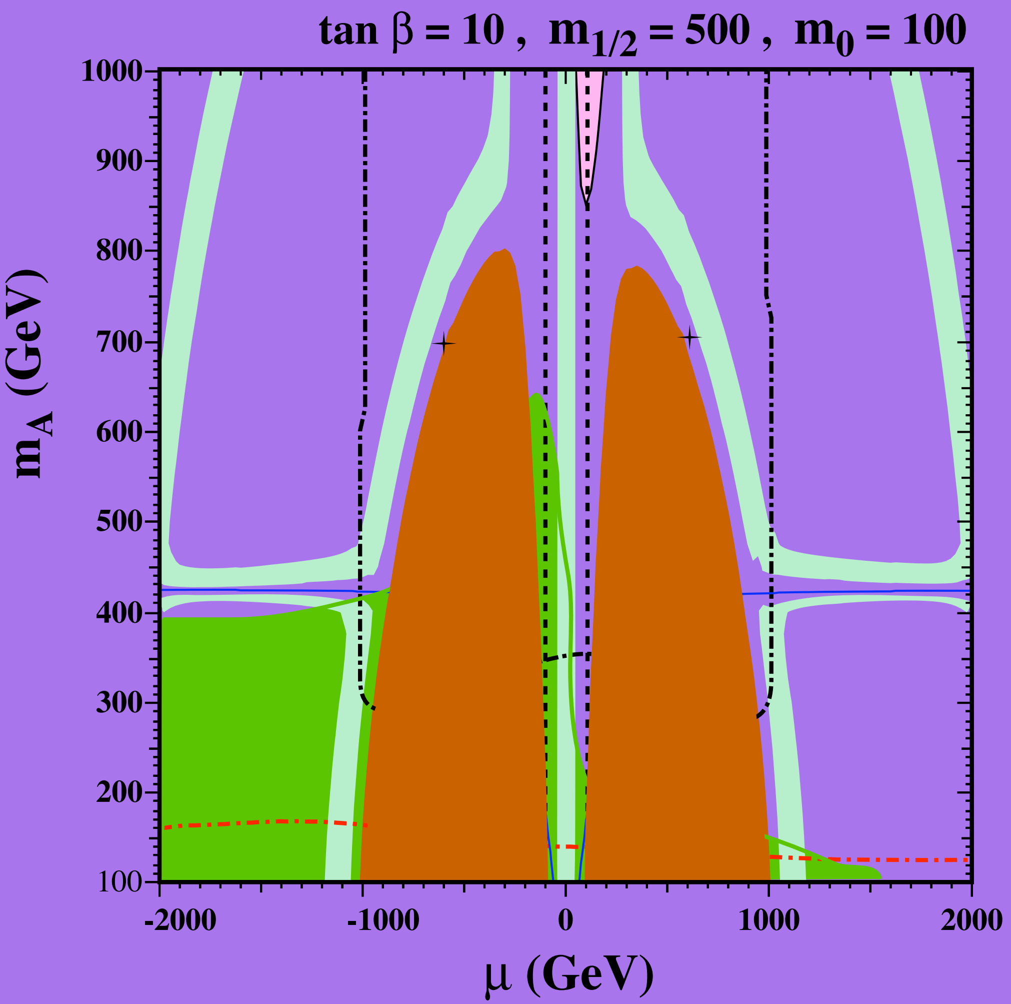


The $m_A - \mu$ plane

+ CMSSM value

Ellis, Olive, Santoso, Spanos



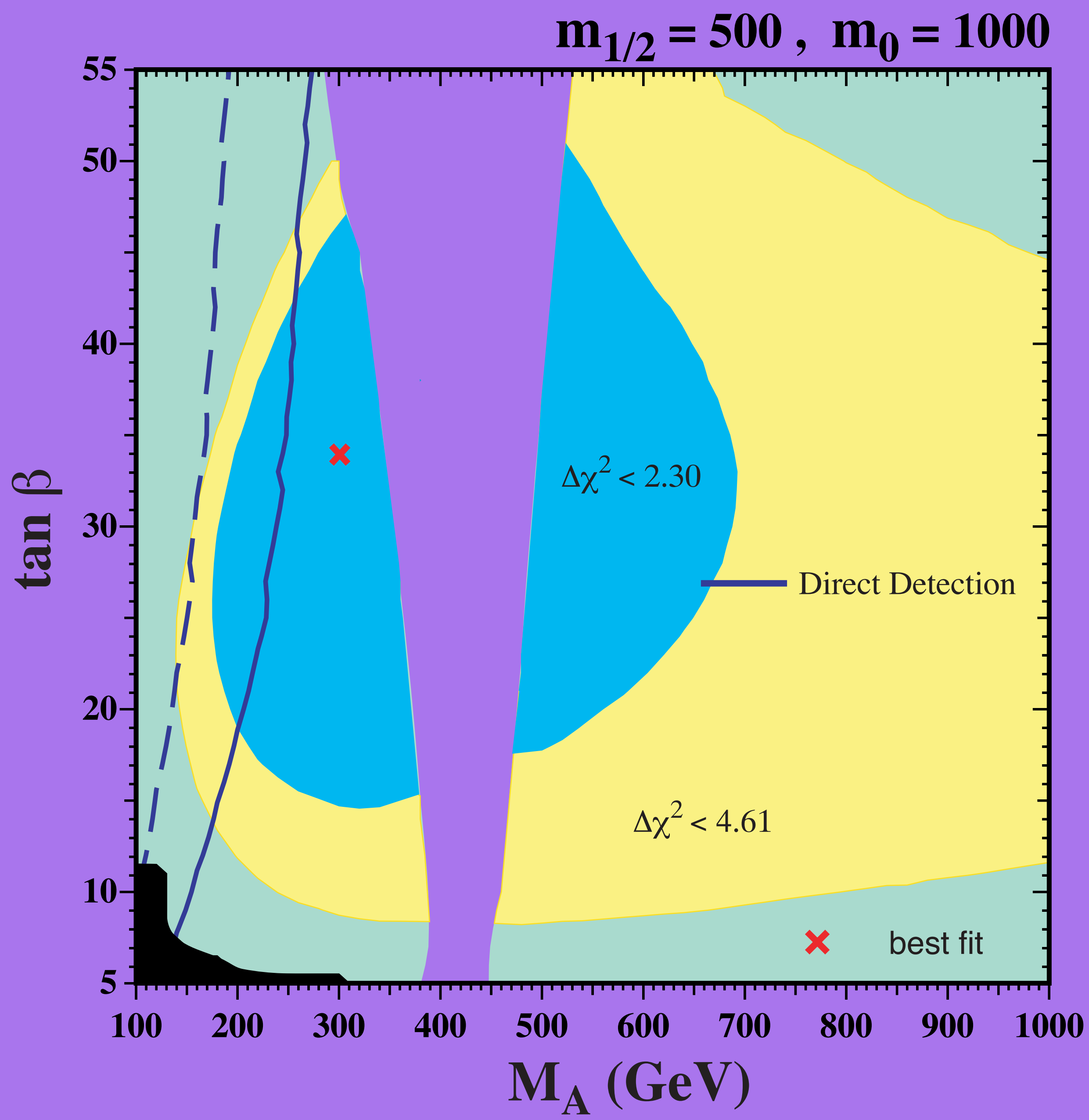


The $m_A - \mu$ plane

+ CMSSM value

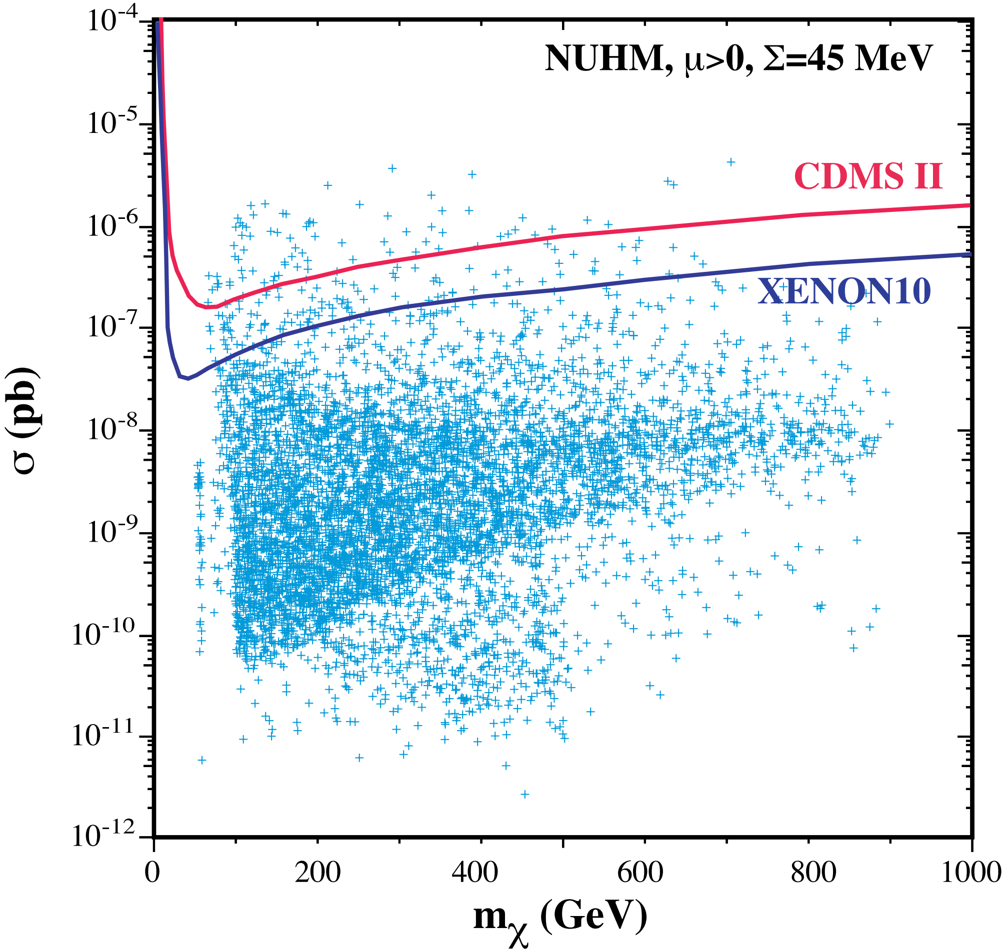
Ellis, Olive, Santoso

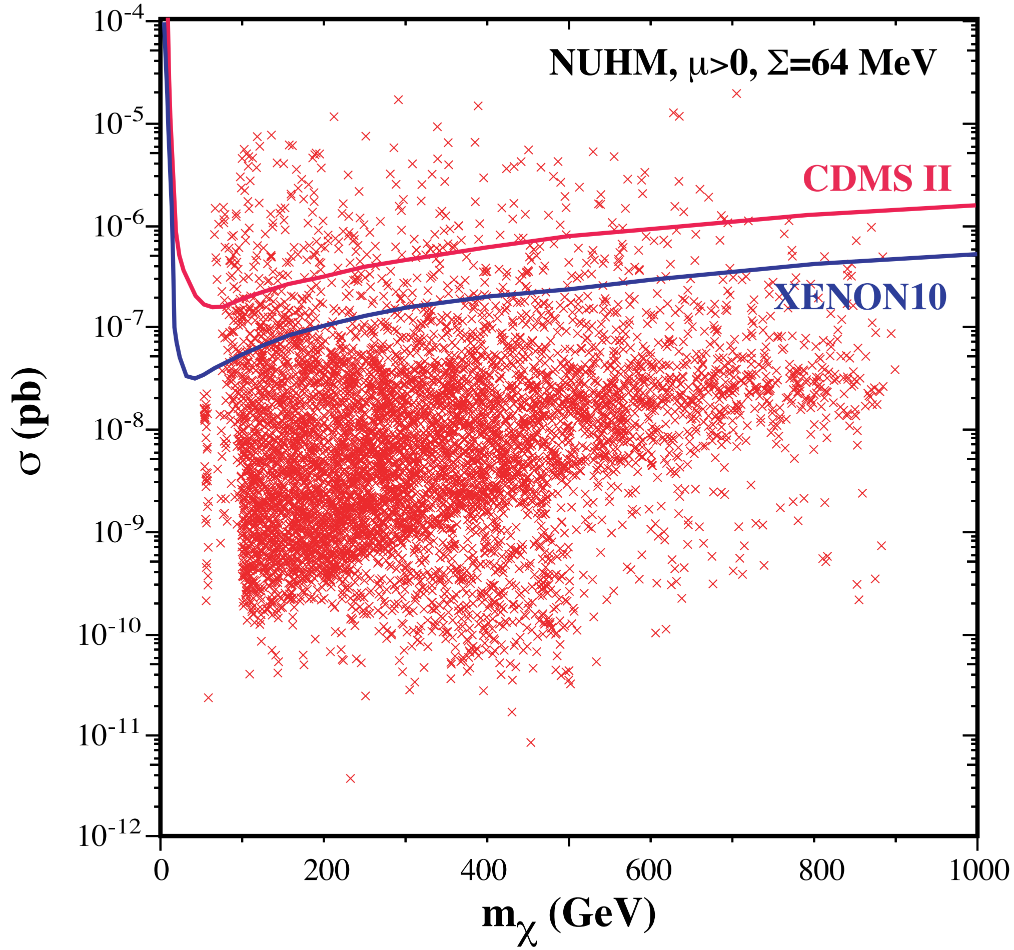
CDM-consistent M_A-tan β planes



Ellis, Hahn, Heinemeyer, Olive, Weiglein

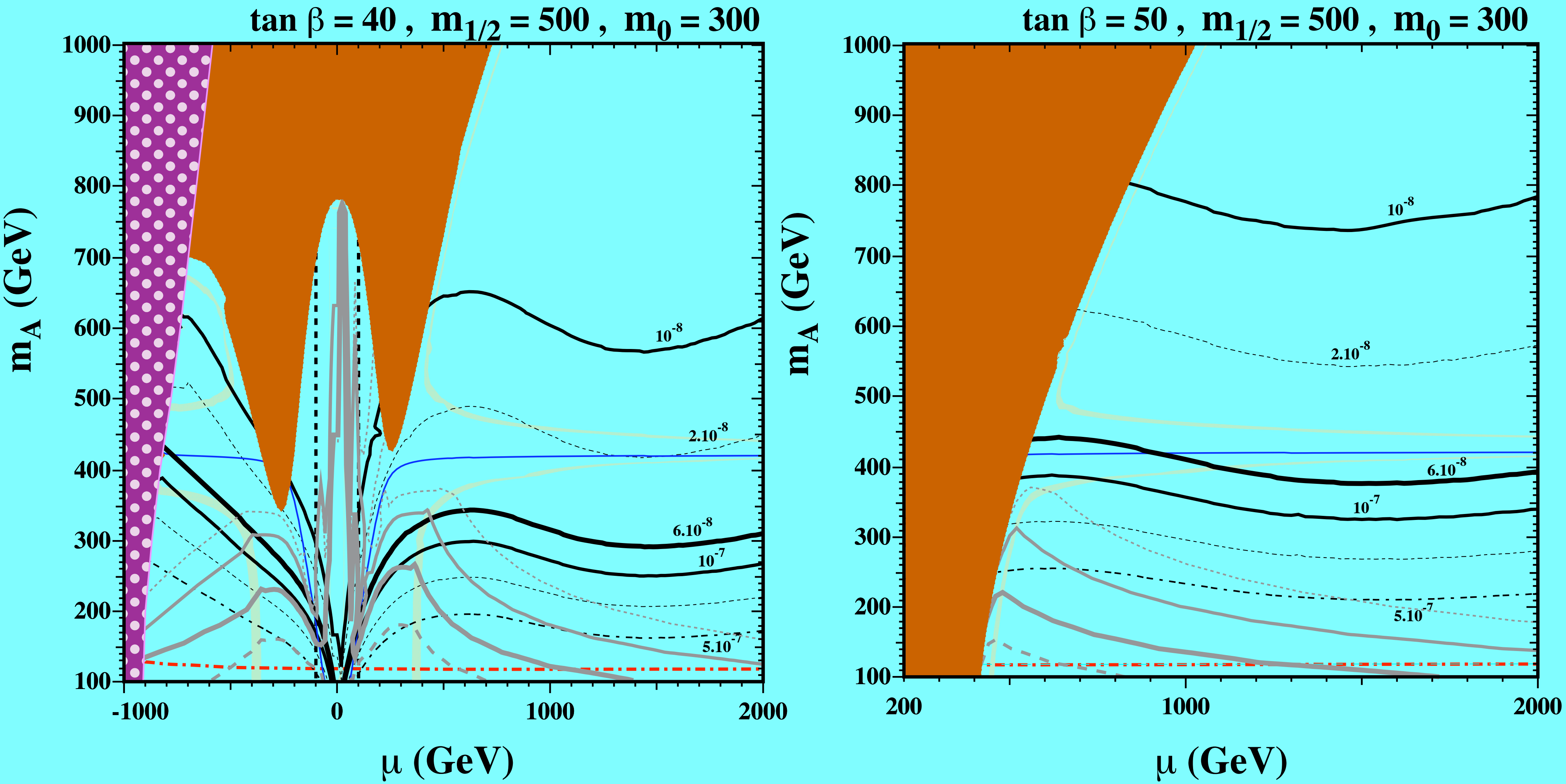
Direct Detection in the NUHM





EOSS

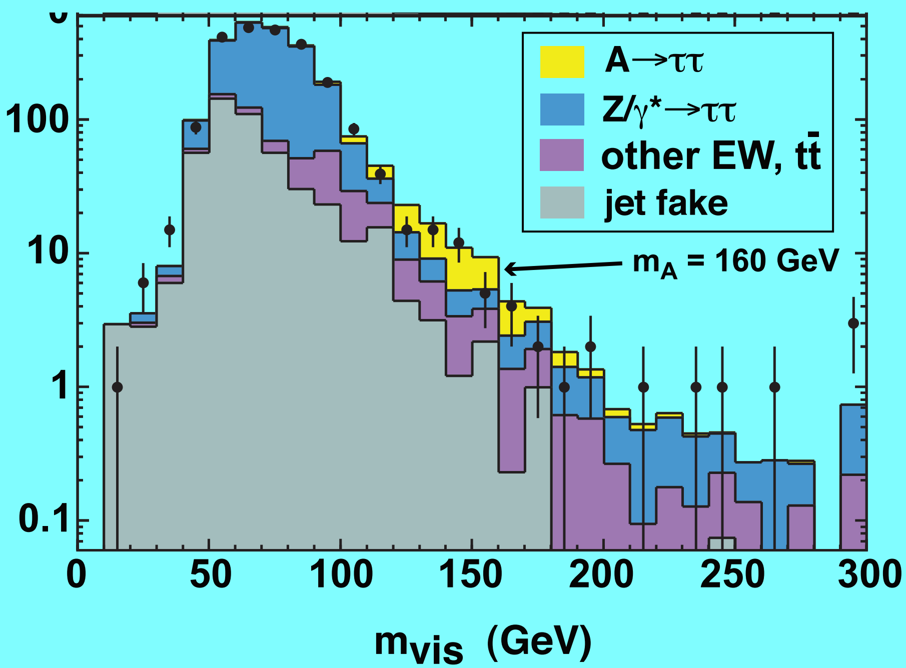
Competition between Direct Detection and B → $\mu^+ \mu^-$

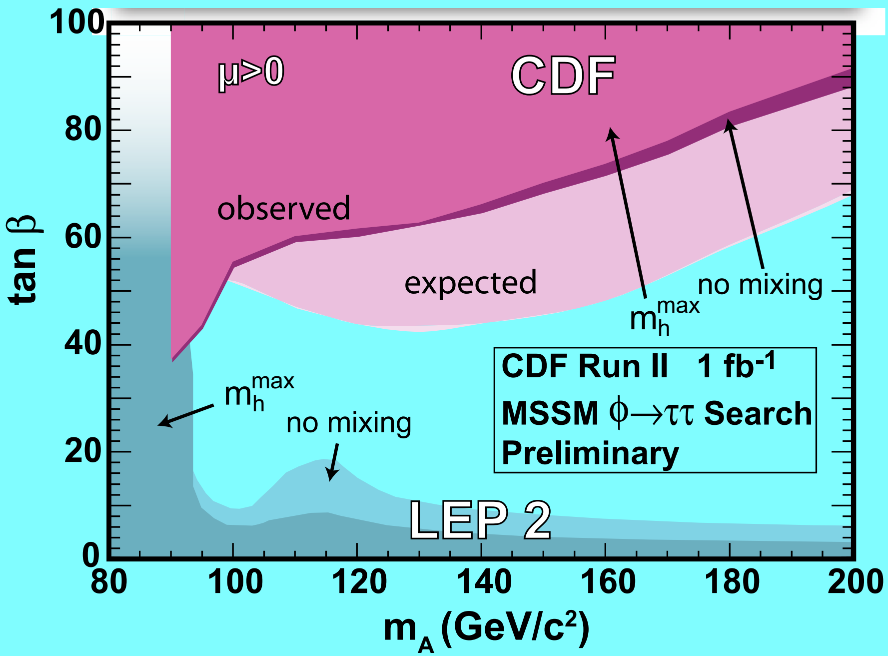


EOSS

Hint of Higgs?

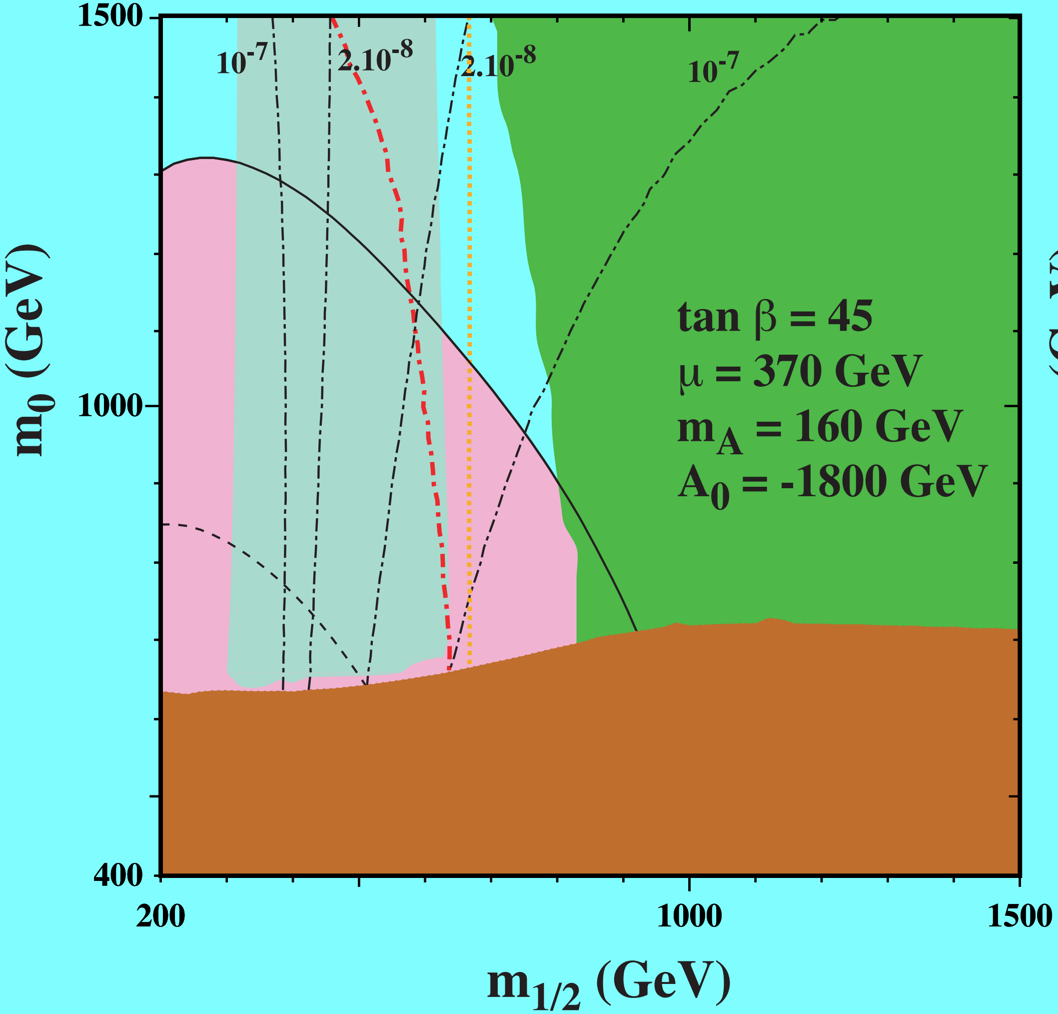
CDF

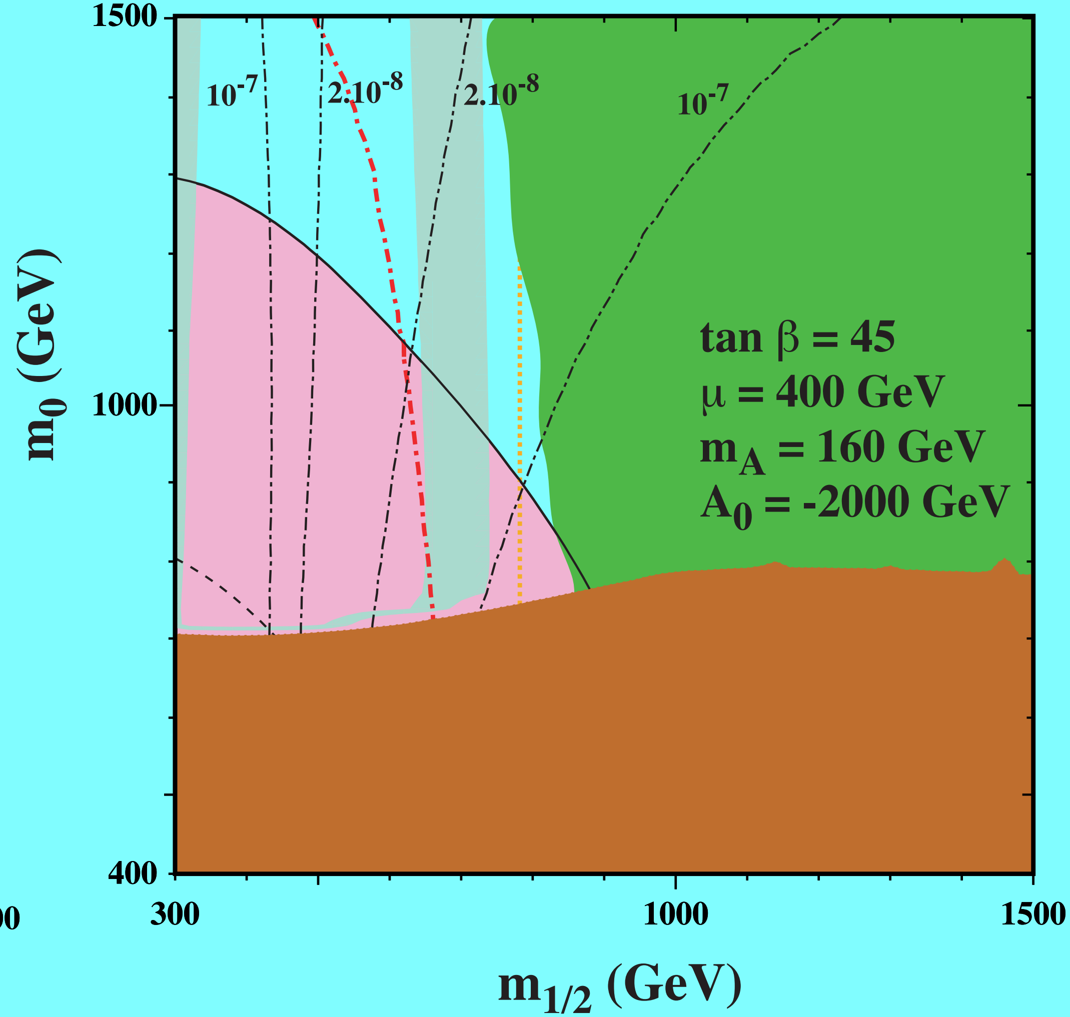




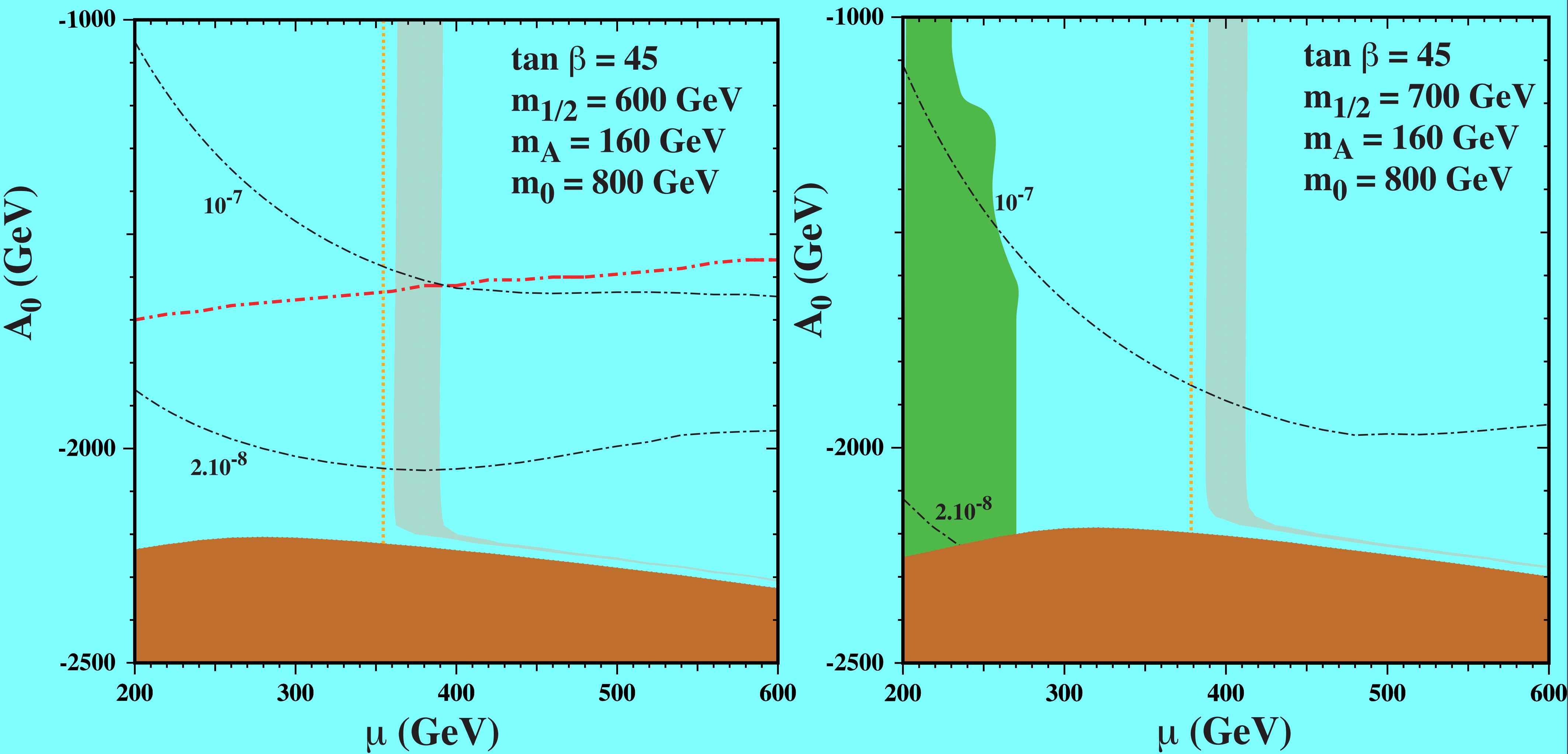
Not possible in CMSSM (light Higgs)
but barely possible in NUHM

NUHM Planes





EHOW


-1000
-2000
-2500
A_0 (GeV)
200
300
400
500
600
μ (GeV)
tan β = 45
$m_{1/2}$ = 600 GeV
m_A = 160 GeV
m_0 = 800 GeV
10^{-7}
2.10^{-8}
tan β = 45
$m_{1/2}$ = 700 GeV
m_A = 160 GeV
m_0 = 800 GeV

EHOW

Hint of Higgs?

- Small M_A and large tan β possible but very constrained in the NUHM (not possible in the CMSSM)
- BR($B_s \to \mu^+ \mu^-$) should be detected soon
- BR($b \to s \gamma$) should show deviations from SM
- Dark Matter should be detected by CDMS and XENON10

Summary

- mSugra models most difficult to access experimental esp. if GDM
- Good indication from indirect sensitivities for `low' energy signal for SUSY.
- Good prospect for Direct detection and $B \to \mu^+ \mu^-$ particularly in non CMSSM models (unless GDM)
- Hint of Higgs should be accompanied by many deviations from the SM